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ARTICLE

Child Development Perspectives

How parent–child brain-to-brain synchrony can inform the study of child development

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Abstract
It is well established that parent–child dyadic synchrony (e.g., mutual emotions, behaviors) can support development across cognitive and socioemotional domains. The advent of simultaneous two-brain *hyperscanning* (i.e., measuring the brain activity of two individuals at the same time) allows further insight into dyadic *neural synchrony*. In this article, we review 16 recent studies of naturalistic, parent–child brain-to-brain synchrony, finding relations with the nature of interactions (collaborative vs. competitive, parent vs. stranger), proximal social cues (gaze, affect, touch, and reciprocity), child-level variables (irritability, self-regulation), and environmental factors (parental stress, family cohesion, and adversity). We then discuss how neural synchrony may provide a biological mechanism for refining broader theories on the developmental benefits of dyadic synchrony. We also highlight critical areas for future study, including examining synchrony trajectories longitudinally, including more diverse participants and interaction contexts, and studying caregivers beyond mothers (e.g., other family members, teachers). We conclude that neural synchrony is an exciting and important window into understanding how caregiver–child dyadic synchrony supports children's social and cognitive development.

KEYWORDS
dyadic brain-to-brain synchrony, naturalistic interactions, parent–child interactions

As one of the most immediate, proximal influences during childhood, caregiver–child interactions are a key context in which children develop crucial social and cognitive skills (Bronfenbrenner & Morris, 1998). Individual differences in developmental outcomes are partially due to differences in parent–child relationships (Eisenberg et al., 2011; Kopp, 1982). Parents can act as important promotive, protective, or risk factors depending on the qualities of caregiving relationships (Feldman, 2020; Masten & Barnes, 2018). More distal environmental factors (e.g., socioeconomic adversity) and child-level factors (e.g., irritability) can also influence parent–child interactions, and therefore, developmental outcomes.

One way researchers examine parent–child relationships is through *dyadic synchrony*, or the extent of coordination, attunement, and reciprocity during interactions (Leclère et al., 2014). Synchrony occurs across modalities, including behavior, physiological state (e.g., matching heart rate), and brain activity (Davis et al., 2017; Feldman, 2007; Mayo & Gordon, 2020). Observed characteristics of high levels of synchrony include mutual responsiveness, positive affect, warmth, and joint attention, and are measured as instances or duration of specific behaviors or global ratings across behaviors. Parent–child dyads commonly fluctuate in both the extent and the aspects of their synchrony. High levels of synchrony require flexibility and adaptation to the specific demands of each context (Lobo & Lunkenheimer, 2020; Lunkenheimer et al., 2011; Mayo & Gordon, 2020; Reyna & Pickler, 2009). Therefore, efforts to maintain high levels of synchrony can be advantageous for children's development, including their emotional well-being and

Abbreviations: dlPFC, dorsolateral prefrontal cortex; EEG, electroencephalography; fNIRS, functional near-infrared spectroscopy; IFG, inferior frontal gyrus; PFC, prefrontal cortex; TPJ, temporoparietal junction.

social functioning, as well as for the cognitive foundations of academic achievement (e.g., self-regulation).

Brain-to-brain, or neural, synchrony refers to the extent to which individuals show temporally linked functional brain activity, measured through *hyperscanning*, a technique used to record the brain activity of two individuals at the same time (Norton et al., 2022). Most research on parent–child hyperscanning has used electroencephalography (EEG), which measures the summed electrical brain activity of groups of neurons, or functional near-infrared spectroscopy (fNIRS), which measures hemodynamic responses to brain activation. Studies that use other techniques, like magnetoencephalography and magnetic resonance imaging, are emerging (e.g., Lin et al., 2023), but in this article, we focus on studies that use EEG and fNIRS because they allow for face-to-face interaction with relatively free movement, making them well-suited for naturalistic interactions with children.

Neural synchrony can be conceptualized in many ways. The more commonly measured *concurrent* synchrony refers to nondirectional, simultaneous brain activity, while *sequential* synchrony is lagged, so brain activity in either individual in the dyad follows the patterns of the other (Marriott Haresign et al., 2022; Wass et al., 2020). Synchrony may be measured in the same (*homologous*) brain regions (e.g., the prefrontal cortices of both individuals) as well as in different (*nonhomologous*) regions (e.g., one individual's frontal cortex and the other's temporoparietal cortex). Identifying the brain regions engaged in synchronous activity can inform theories of how dyads process interactions and how these processes relate to children's outcomes. In several studies, neural synchrony was associated with observed forms of behavioral synchrony, leading researchers to theorize that behavioral and neural synchrony can mutually influence and facilitate one another (Levy et al., 2021). Similarly, in some studies, neural synchrony was related to individual differences in children's characteristics, contexts, and developmental outcomes. Therefore, studies of brain-to-brain synchrony may provide crucial insights into the biological underpinnings of behavioral synchrony and how it can support children's development across domains.

In this article, we describe findings from 16 studies (conducted between 2018 and 2023) of naturalistic parent–child brain-to-brain synchrony in nonclinical populations of typically developing children from birth to 18 years.[1] Our primary aim is to identify potential correlates of parent–child brain-to-brain synchrony, including interaction characteristics, proximal behaviors, child-level variables, and distal environmental variables. In doing so, we discuss how hyperscanning uniquely contributes to understanding parent–child dyadic synchrony and general interaction. For each study, we summarize the available demographics of participants (see Table 1) and brain-to-brain synchrony methods (see Table 2). Finally, we highlight important avenues for investigation to further establish the contributions of neural synchrony to the field of child development.

[1]We consider our work to be a narrative review rather than a systematic review. To identify articles, we used the following search terms in Academic Search Ultimate, PsycInfo, ERIC, and Google Scholar: *interbrain neural synchrony, interbrain connectivity, interbrain coupling, neural synchrony, brain-to-brain synchrony, interbrain synchronization, neural entrainment*, and *interbrain coherence*. We identified additional papers by backward searching in the references of articles from the initial search. Articles were included if they were empirical studies of EEG or fNIRS hyperscanning with parents and their children (from birth to 18 years) and did not target clinical populations.

PROXIMAL CIRCUMSTANCES AND BEHAVIORS

Interactive partner

Emerging evidence suggests that the parent–child relationship is a unique context for neural synchrony. In an fNIRS study of 5- to 9-year-olds, synchrony was observed in approximately the dorsolateral prefrontal cortex (dlPFC), which is associated with emotion regulation and joint attention, and the frontopolar cortex, but only during parent–child cooperative video games (Reindl et al., 2018). No synchrony was observed during parent–child competitive, stranger-child cooperative, or stranger–child competitive games. In another fNIRS study, of 10- to 18-year-olds, greater synchrony was observed globally across the prefrontal cortex (PFC) and specifically in the orbitofrontal and right superior PFC regions in mother-daughter dyads compared to stranger–child dyads during both competitive and cooperative video games (Reindl et al., 2022). Although autonomic nervous system synchrony (heartbeat cofluctuation) and behavioral synchrony (response time coordination) were higher than shuffled data for both dyads, mother–daughter dyads did not have significantly greater autonomic nervous system or behavioral synchrony than stranger–child dyads. Thus, synchrony was higher between mothers and daughters only at the neural level. Increased familiarity may facilitate higher levels of brain-to-brain synchrony, suggesting that parent–child interaction is a biobehaviorally unique context.

Type of interaction

Three fNIRS studies indicate that the nature of social interactions relates to brain-to-brain synchrony. In one study of 5- to 6-year-olds, cooperative problem solving was associated with greater synchrony in the temporoparietal and lateral PFC regions among mother–child dyads (Nguyen et al., 2020) and in the bilateral dlPFC and left temporoparietal junction (TPJ) among father–child dyads (Nguyen, Schleihauf, et al., 2021). Neither competitive interactions nor independent problem solving were connected to brain-to-brain synchrony (Nguyen et al., 2020; Nguyen, Schleihauf, et al., 2021; Reindl et al., 2018). However, in the previously mentioned study (of 10- to 18-year-olds; Reindl et al., 2022), brain-to-brain

TABLE 1 Summary of sample characteristics.

Study	# of dyads	Parent	Children's gender	Children's age	Location	Race/ ethnicity	Socioeconomic status
Azhari et al. (2019)	31	Mother	13 girls, 18 boys	3–4 years	Singapore	No info	No info
Azhari et al. (2023)	60	Parent (31 mothers, 29 fathers)	24 girls, 36 boys	2–4 years	Singapore	No info	No info
Deng et al. (2022)	29	Parent (13 mothers, 16 fathers)	7 girls, 22 boys	11–14 years	Urban Shenzhen, China	No info	90%+ mother and father college degree
Endevelt-Shapira and Feldman (2023)	60	Mother	25 girls, 35 boys	5–12 months	Israel	All Caucasian Jewish	All middle class
Hoyniak et al. (2021)	115	Parent (108 mothers, 5 fathers, 2 other)	52 girls, 63 boys	4–5 years	U.S.	69% White, 21% Black, 10% multiracial	31% < \$39 k, 36% \$40-99 k, 33% > \$100 k
Morgan et al. (2023)	41	Mother	23 girls, 18 boys	10–42 months	Pittsburgh, U.S.	61% White, 15% Black, 12% Asian, 12% multiracial	85% college degree, 90% married
Nguyen et al. (2020)	42	Mother	23 girls, 19 boys	5–6 years	Unclear	All White	57% college degree, 43% vocational
Nguyen, Abney, et al. (2021)	69	Mother	33 girls, 36 boys	4–6 months	Vienna, Austria	All White	57% college degree, middle- to upper-class
Nguyen, Schleihauf, et al. (2021)	66	Father	31 girls, 35 boys	5–6 years	Eastern Germany	All White	67% monthly income >3 k€, middle- to upper-class
Nguyen et al. (2023)	55	Mother	25 girls, 30 boys	4–24 months	Vienna, Austria	Mostly or all White	76% college degree
Quiñones-Camacho et al. (2020)	116	Parent (110 mothers, 6 other)	54 girls, 62 boys	4–5 years	U.S.	71% White, 23% Black	14% < \$20 k, 29% \$21–60 k, 25% \$61–100 k, 32% > \$101 k
Quiñones-Camacho et al. (2021)	151	Parent (144 mothers, 7 other)	70 girls, 81 boys	4–7 years	U.S.	68% White, 23% Black	47% < \$60 k, 36% \$61–120 k, 17% > \$120 k
Reindl et al. (2018)	33	Parent (30 mothers, 3 fathers)	14 girls, 19 boys	5–9 years	Germany	No info	No info
Reindl et al. (2022)	34	Mother	34 girls	10–18 years	Germany	No info	No info
Santamaria et al. (2020)	15	Mother	7 girls, 8 boys	10.5 months	U.K.	No info	No info
Schwartz et al. (2022)	62	Mother	35 girls, 27 boys	10–14 years	Israel	No info	All middle-class

TABLE 2 Summary of brain-to-brain synchrony methods.

Study	Imaging	Interaction condition(s)	Control condition(s)	Brain region(s) of interest
Azhari et al. (2019)	fNIRS	Film clips with child on lap (two positive, one negative)	N/A	Clustered left and right frontal PFC, left and right medial PFC (total 16 channels per person)
Azhari et al. (2023)	fNIRS	Toy play (coded for joint and non-joint)	N/A	Clustered left and right frontal PFC, left and right posterior PFC (total 18 channels per person)
Deng et al. (2022)	EEG	Side-by-side film clips (positive, negative, and neutral)	N/A	Frontal, central, parietal (total 32 channels per person)
Endevelt-Shapira and Feldman (2023)	EEG	No-toy free play	N/A	Temporal, occipital-temporal, central, frontal (total 16 channels per person)
Hoyniak et al. (2021)	fNIRS	Frustrating tangram puzzles, toy play recovery	N/A	Global dorsolateral PFC (total 20 channels per person)
Morgan et al. (2023)	fNIRS	Toy play	N/A	Clustered anterior medial PFC, lateral PFC, TPJ (total 8 parent and 12 child channels)
Nguyen et al. (2020)	fNIRS	Face-to-face tangram puzzles (cooperative and separate)	Rest (eyes closed)	Clustered left and right dorsolateral PFC, left and right TPJ (total 16 channels per person)
Nguyen, Abney, et al. (2021)	fNIRS	No-toy free play, relaxing aquatic video (side-by-side and with child on lap)	N/A	Clustered IFG, medial PFC, lateral PFC (total 22 channels per person)
Nguyen, Schleihauf, et al. (2021)	fNIRS	Face-to-face tangram puzzles (cooperative and separate)	Rest (eyes closed)	Clustered left and right dorsolateral PFC, left and right TPJ (total 16 channels per person)
Nguyen et al. (2023)	fNIRS	No-toy free play, relaxing aquatic video (side-by-side and with child on lap)	N/A	Clustered IFG, medial PFC, lateral PFC (total 22 channels per person)
Quiñones-Camacho et al. (2020)	fNIRS	Frustrating tangram puzzles, toy play recovery	N/A	Middle and IFG (total 20 channels per person)
Quiñones-Camacho et al. (2021)	fNIRS	Frustrating tangram puzzles, toy play recovery	N/A	Middle and IFG (total 20 channels per person)
Reindl et al. (2018)	fNIRS	Side-by-side video games (cooperative and competitive)	Stranger interactions	PFC (total 22 channels per person)
Reindl et al. (2022)	fNIRS	Side-by-side video games (cooperative and competitive)	Relaxing aquatic video, stranger interactions	Global PFC and 4 statistically-determined subregions (total 22 channels per person)
Santamaria et al. (2020)	EEG	Positive and negative maternal affect toward novel toys	Separate toy play	Global frontal, central, and parietal (total 16 channels per person)
Schwartz et al. (2022)	EEG	Face-to-face and remote video-chat conversations	Rest (staring at wall)	Clustered left and right frontal, left and right central, left and right temporal (total 32 channels per person)

Abbreviations: EEG, electroencephalography; fNIRS, functional near-infrared spectroscopy; Hb, deoxygenated hemoglobin; HbO, oxygenated hemoglobin; IFG, inferior frontal gyrus; PFC, prefrontal cortex; TPJ, temporo-parietal junction.

[a]This column includes dyad-level nuisance variables in individual comparisons, as well as methods for correcting for multiple comparisons.

synchrony was observed during both cooperative and competitive games, which could suggest that mutually shared goals may foster higher levels of neural attunement in younger children.

Proximity and touch

Important communicative signals appear to be related to synchrony in the PFC and inferior frontal gyrus (IFG),

Frequency range of interest	Measure of synchrony	Statistical controls[a]
0.01–0.20 Hz	HbO dynamic time warping and correlations	Child's gender, mother's age, video valence, video complexity, audio intensity, video pitch, false discovery rate for multiple comparisons
0.01–0.20 Hz	HbO and Hb cross-correlations	Simulated data for one random dyad member, false discovery rate for multiple comparisons
Gamma (31–40 Hz)	Phase-locking values	Shuffled dyads, child's age, parent's age, child's gender, parent's gender, parent–child gender combination, only-child status, father's education, mother's education, child's depressive level, child's anxiety level, child's social support, parent's depressive level, parent's anxiety level, parental involvement, Bonferroni correction for multiple comparisons
Theta (4–7 Hz)	Weighted phase lag index	Shuffled dyads, excluded data, false discovery rate for multiple comparisons
Unspecified	HbO correlations	Shuffled pairs, autoregression, child gender, parental role, false discovery rate for multiple comparisons
Unspecified	HbO correlations	Shuffled dyads, autoregression, child age, false discovery rate for multiple comparisons
0.02–0.10 Hz	HbO Morlet wavelet transform coherence	Shuffled dyads, child's gender, mother's age, child's age, maternal education, task order, task familiarity, Tukey's honest significant difference for multiple comparisons, false discovery rate for multiple comparisons
0.012–0.312 Hz	HbO and Hb Morlet wavelet transform coherence	Shuffled dyads, condition duration, Tukey's honest significant difference for multiple comparisons
0.08–0.10 Hz	HbO Morlet wavelet transform coherence	Shuffled dyads, false discovery rate for multiple comparisons, Tukey's honest significant difference
0.063–0.167 Hz	HbO and Hb Morlet wavelet transform coherence	Tukey's honest significant difference for multiple comparisons
Unspecified	HbO correlations	Shuffled pairs, autoregression, false discovery rate for multiple comparisons
Unspecified	HbO correlations	Shuffled pairs, autoregression, false discovery rate for multiple comparisons
0.08–0.50 Hz	HbO Morse wavelet transform coherence	Shuffled dyads, child's age, child's gender, response times (competitive only), joint wins (cooperative only) false discovery rate for multiple comparisons
0.08–0.50 Hz	HbO bivariate wavelet coherence density	Shuffled dyads, child's age
Alpha (6–9 Hz)	Partial directed coherence and phase-locking values	Shuffled dyads, shuffled epochs, proportional thresholding, loudness, Tukey's honest significant difference for multiple comparisons
Beta (13.5–29.5 Hz)	Weighted phase lag index	Shuffled dyads, shuffled epochs, beta power spectral density, Bonferroni correction for multiple comparisons

areas associated with shared emotion. In a study that used fNIRS, researchers measured synchrony among mother–infant dyads in three contexts: distal joint-watching (side-by-side videos), proximal joint-watching (infants on mothers' laps during videos), and free play (Nguyen, Abney, et al., 2021). Homologous synchrony was greater in the lateral and medial PFC during proximal watching and free-play conditions than during the distal watching condition. Mothers' affectionate touch during play was also positively associated with synchrony in these brain regions, leading the researchers to conclude that proximity and affectionate touch may foster mutual engagement during parent–child interactions, particularly during infancy when children rely heavily on external care and regulation.

Another study used EEG on 10- to 14-year-olds to examine beta-band synchrony between mothers and children in face-to-face versus remote video chat conversations about planning theoretical fun trips (Schwartz et al., 2022). The researchers focused on beta-band activity given its links with parent–child attachment, communication between emotionally close individuals, empathy, and social engagement. During video chats, brain-to-brain synchrony was found only between mothers' right-frontal and children's left-temporal regions. In contrast, face-to-face interactions elicited synchrony in multiple combinations of homologous and nonhomologous frontal and temporal regions across hemispheres. Mothers' right frontal cortexes emerged as a special hub synchronizing with all children's brain areas examined, indicating strong contributions to interbrain dynamics.

Gaze

The same study of video chat versus in-person interactions (Schwartz et al., 2022) also examined relations between behavior and homologous synchrony. Interactions were micro-coded (i.e., second-by-second rating of behaviors) for parents' and children's gaze and macro-coded (i.e., global rating of behaviors) for children's empathic social engagement (a composite of children's gaze, openness to parents, involvement, approach, empathy, and collaboration). During face-to-face conversation only, shared gaze correlated with temporal region synchrony, and children's empathetic engagement correlated with frontal synchrony, suggesting a stronger relation between behavior and brain-to-brain synchrony during face-to-face interactions.

Reciprocity

Turn-taking has also been associated with neural synchrony. In an fNIRS study with mother-infant dyads, more frequent vocal turn-taking during play was related to greater synchrony in the medial PFC, particularly in the first 2 min (Nguyen et al., 2023). The medial PFC, which is associated with social cognition and mentalizing abilities, may facilitate the social attunement required for turn-taking. Moreover, turn-taking and neural synchrony may be more strongly related at the beginning of interactions, as mothers and infants adapt to the context together.

More general interactive responsivity also correlates with neural synchrony, as measured using EEG. In one study, higher levels of observed maternal sensitivity (warmth, acceptance, and responsiveness) during no-toy play was related to synchrony in mothers' right frontal and infants' right temporal regions as measured using EEG theta-frequency activity, which has been linked with processing emotional cues and emotionally salient behaviors (Endevelt-Shapira & Feldman, 2023). When mothers were more intrusive (dictating the interaction), theta-frequency synchrony in the mothers' left frontal and infants' right temporal regions was lower. The researchers posit that because mothers have more developed regulation skills, their frontal cortices help regulate their infant's brain; over time, this external regulation facilitates independent regulation.

Emotional valence

Several studies suggest a relationship between emotional valence and brain-to-brain synchrony. In one, mothers were instructed to show positive or negative emotions toward unfamiliar objects in front of their infants (Santamaria et al., 2020). EEG-measured alpha-band synchrony in the frontal, central, and parietal regions was greater when mothers showed positive versus negative emotions. In an investigation of directionality during synchrony, mothers had a stronger influence during positive affect, while infants' influence was greater during negative affect. This suggests that neural synchrony is sensitive to the affective states of both parties, but caution is warranted because the study had only 15 participants.

A separate study, which used fNIRS with 1- to 3-year-olds, assessed whether affect matching during play was associated with neural synchrony in the children (Morgan et al., 2023). After correcting for multiple comparisons, the study yielded no significant findings, so caution is warranted. However, when mother–child dyads displayed simultaneously high levels of positive affect, synchrony was somewhat higher in the right lateral PFC of mothers and children (which is linked with emotion regulation); low levels of positive affect matching were not related to neural synchrony. When children displayed high levels of positive affect and mothers displayed low levels of positive affect, the study saw some synchrony in mothers' right lateral PFC and children's left TPJ (which is associated with mentalizing abilities). Age moderated this relation, with high levels of positive affect matching more strongly related to synchrony in older children. More research is needed to understand how neural synchrony changes as emotional expressions fluctuate during parent–child interactions.

CHILD-LEVEL VARIABLES

Children's irritability

One fNIRS study examined how preschoolers' irritability is related to brain-to-brain synchrony (Quiñones-Camacho et al., 2020). Mother–child dyads completed two tasks related to coregulation: a mild frustration-eliciting task and recovery-free play. Higher levels of mother-reported children's irritability were correlated with lower lateral PFC synchrony during play. Children's irritability can negatively affect parent–child dynamics by eliciting more negative responses from parents, particularly during and following stressors, which may make synchrony more difficult or undesirable as a result of the negative valence.

Children's self-regulation

In an fNIRS study of 5- to 9-year-olds, frontopolar cortex synchrony during a cooperation task mediated the association between parent-reported use of situational reappraisal (adaptive emotion regulation strategy) and children's emotion regulation skills (Reindl et al., 2018). Parents' adaptive regulation strategies may foster neural attunement when interacting with their children. In turn, synchrony could promote children's self-regulation through observation of adaptive emotion regulation strategies while practicing coregulation with a more skilled individual. However, it is unclear how children's situational self-regulation may relate bidirectionally to neural synchrony and parents' regulatory strategies.

Children's behavioral outcomes

We identified only one study that examined how parent–child brain-to-brain synchrony relates to later developmental outcomes. In a longitudinal fNIRS study of preschoolers, higher levels of mother–child PFC synchrony during recovery from a frustration-eliciting task were related to greater decreases in mother-reported internalizing, but not externalizing, symptoms among children 18 months later (Quiñones-Camacho et al., 2021). Brain-to-brain synchrony during the frustration task itself was not associated with internalizing changes. The authors speculate that the relatively stress-free play facilitated coregulation and promoted children's recovery from frustration. Thus, dyads' synchrony following a stressor may act as a protective factor, encouraging resilience through coregulation to manage internalizing behaviors (Feldman, 2020).

DISTAL ENVIRONMENTS AND CONTEXTS

Family environment

One small EEG study of parent–adolescent dyads focused on family cohesion (i.e., closeness) as a correlate of neural synchrony in gamma-band activity, chosen for its association with emotional valence (Deng et al., 2022). During film clips that elicited positive emotions, dyads with high levels of family cohesion showed greater gamma-band synchrony in parietal regions than seen in dyads with low levels of family cohesion. Dyads with high and low levels of family cohesion did not differ in neural synchrony during negative or neutrally valenced film clips. Higher levels of family cohesion may foster positive emotional attunement between family members and promote synchrony across parietal regions (which is linked with emotion regulation) during situations that elicit positive emotions.

Parenting attitudes and parents' cognitions

One fNIRS study of fathers and preschoolers investigated parenting attitudes in relation to neural synchrony (Nguyen, Schleihauf, et al., 2021). When fathers expressed more positive attitudes about their parental role (e.g., believing they should be involved with their children), father–preschooler synchrony was higher in the bilateral dlPFC and bilateral TPJ during a cooperative task. This is consistent with findings that attitudes and cognitions regarding parenting roles are associated with parenting behaviors such as involvement (Macon et al., 2017). Fathers who believe more in the importance of their involvement are likely to spend more time engaging with and developing attunement to children's behaviors and emotions, which promotes synchrony.

Three fNIRS studies identified parental stress as a correlate of brain-to-brain synchrony. In one study, mother-reported general stress was related to lower levels of synchrony with preschoolers in the bilateral dlPFC and bilateral TPJ during problem-solving tasks (Nguyen et al., 2020). Similarly, in another study, mothers who reported more parenting stress (i.e., how overwhelmed they felt about parenting) displayed less synchrony in the dlPFC and the medial left IFG when watching videos with their preschoolers (Azhari et al., 2019). The third study, of parents and their 2- to 4-year-olds, examined neural synchrony during toy play (Azhari et al., 2023). More parenting stress was associated with reduced synchrony in a right-lateralized frontal cluster associated with higher-order cognitive functions, emotion regulation, working memory, and attention. However, parenting stress was also associated with *greater* synchrony in a left-lateralized frontal cluster related to task management. The authors posit that dyads with higher levels of parenting stress may have more dissimilarity in emotion processing and may also rely more on planning-related brain regions to sustain play.

Adversity

In yet another fNIRS study of mothers and their preschoolers, greater sociodemographic risk (a composite of neighborhood deprivation, income, use of social services, single-parent status, and parental education) was related to lower levels of mother–child synchrony in the lateral PFC during a frustration-eliciting task (Hoyniak et al., 2021). Reflecting the family stress model (Conger & Donnellan, 2007), this study suggests that lower levels of neural synchrony are a mechanism by which environmental risk affects developmental outcomes. Sociodemographic adversity often increases parents' baseline stress levels, which can multiply momentary frustration and ultimately limit their capacity to coregulate productively.

CONCLUSIONS

Research using hyperscanning is relatively recent, but the number of such studies is growing rapidly, and the work provides unique insights and avenues for further inquiry into parent–child synchrony. Much like behavioral and affective synchrony, brain-to-brain synchrony appears to reflect multiple observed social cues and predict some developmental outcomes. Furthermore, individual differences in synchrony appear to be influenced by children's traits as well as by proximal and distal environments, which is consistent with the bioecological model of development (Bronfenbrenner & Morris, 1998). Critical insights into the cognitive and affective mechanisms that drive observed neurobiological synchrony may be gained by investigating the regions (homologous and nonhomologous) and bandwidths that demonstrate synchrony. Brain-to-brain synchrony may also provide a relatively direct, unbiased measure of parent–child relationships compared to survey or observational measures. Thus, this approach opens many new lines of inquiry into children's interactions with caregivers and highlights the underlying social, cognitive, and biological mechanisms driving development.

While many gaps remain in our knowledge of parent–child brain-to-brain synchrony, a few areas warrant urgent attention. First, as in developmental science broadly, most hyperscanning studies have focused on mothers; very few have included more than a few fathers or other parental figures—although researchers have increasingly focused on recruiting fathers as study participants (e.g., Schulz et al., 2023; Yaremych & Persky, 2023). Biases among families and researchers alike can lead to the assumption that mothers are the go-to caregivers, but family and caregiving structures are diverse; many children have several primary caregivers or nonbiological caregivers who uniquely influence development (Owen et al., 2013). Children are exposed to multiple *modes of co-regulation* (Feldman, 2007), and as such, it is important to understand whether correlates of brain-to-brain synchrony vary across caregivers. This understanding can also help address questions regarding the promotive and protective effects of brain-to-brain synchrony. For example, do children who exhibit greater brain-to-brain synchrony with multiple caregivers have better outcomes than children who have greater synchrony with only one caregiver? Does a high level of synchrony with at least one caregiver offset potential negative effects related to a low level of synchrony with another caregiver?

Second, although several of the studies we reviewed were conducted outside the United States, when race or ethnicity was reported, most participants were White, which reflects wider biases in human subjects and neuroimaging research. For example, EEG and fNIRS results are affected by hair texture, and fNIRS results are also affected by scalp and hair melanin, which often contributes to the systematic exclusion of Black participants with thick, coily hair (Kwasa et al., 2023; Ricard et al., 2023; Webb et al., 2022), and this limits the representativeness of findings. Furthermore, the nature of parent–child interactions often differs cross-culturally, which may have implications for the social and behavioral factors that facilitate synchrony (Wass & Goupil, 2022). Thus, it is critical that studies of parent–child synchrony intentionally recruit more ethnically, racially, and culturally diverse participants and, simultaneously, that equipment makers and researchers develop more effective methods to collect high-quality data across hair types. These approaches are key to understanding if and how correlates of brain-to-brain synchrony differ across sociocultural contexts.

Third, most hyperscanning studies have been cross-sectional. Although more expensive and logistically challenging, longitudinal studies can shed light on trajectories of parent–child brain-to-brain synchrony. Research on parent–child behavioral synchrony suggests relative stability across development (Feldman, 2010), but it is unclear whether brain-to-brain synchrony is similarly stable. It also remains unclear whether associations between brain-to-brain synchrony and children's outcomes are similar in strength across time, given behavioral variation and changes in the brain across developmental periods (Murray et al., 2015). Longitudinal studies would also allow researchers to examine bidirectional and cross-lagged associations between brain-to-brain synchrony and its correlates. Additionally, longitudinal studies are more conducive to revealing moderators and mediators between parent–child brain-to-brain synchrony and children's outcomes.

Finally, we do not know whether brain-to-brain synchrony is adaptive across circumstances. In the behavioral synchrony literature, there is consensus that mutual negative affect is a distinct process of negative synchrony, which tends to be harmful for relationships and thus is a potential risk factor for children's outcomes (Davis et al., 2017; Harrist & Waugh, 2002). In theories of emotional contagion and affective linkage, shared negative emotions can amplify each other (Elfenbein, 2014). Thus, lower levels of synchrony could be advantageous when one member of a parent–child dyad is upset. For example, when parents are experiencing high levels of stress, do they exhibit less synchrony with children in emotion-processing brain regions as a possible protective mechanism? Might a child unconsciously reduce their synchrony with a caregiver whose parenting practices are harsher (e.g., abusive)? All the studies we reviewed examined only the correlates of synchrony, but the question of how neural synchrony may moderate relations between developmental experiences and outcomes is one that merits exploration.

In summary, studies of parent–child brain-to-brain synchrony appear to have much to contribute to the broader study of parent–child interaction. Emerging correlates of neural synchrony range from individual characteristics to parental attitudes and environmental factors. Among the many avenues for investigation are additional correlates, moderators, and longitudinal trajectories, which can produce valuable insights into children's intertwined social, cognitive, and biological development.

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