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SPECIAL ISSUE

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In sync with your child: The potential of parent–child electroencephalography in developmental research

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Abstract

Healthy interaction between parent and child is foundational for the child's socioemotional development. Recently, an innovative paradigm shift in electroencephalography (EEG) research has enabled the simultaneous measurement of neural activity in caregiver and child. This dual-EEG or hyperscanning approach, termed parent–child dual-EEG, combines the strength of both behavioral observations and EEG methods. In this review, we aim to inform on the potential of dual-EEG in parents and children (0–6 years) for developmental researchers. We first provide a general overview of the dual-EEG technique and continue by reviewing the first empirical work on the emerging field of parent–child dual-EEG, discussing the limited but fascinating findings on parent–child brain-to-behavior and brain-to-brain synchrony. We then continue by providing an overview of dual-EEG analysis techniques, including the technical challenges and solutions one may encounter. We finish by discussing the potential of parent–child dual-EEG for the future of developmental research. The analysis of multiple EEG data is technical and challenging, but when performed well, parent–child EEG may transform the way we understand how caregiver and child connect on a neurobiological level. Importantly, studying objective physiological measures of parent–child interactions could lead to the identification of novel brain-to-brain synchrony markers of interaction quality.

KEYWORDS

brain development, EEG, hyperscanning, neural synchrony, parent–child interaction

1 | INTRODUCTION

Healthy interaction between parent and child is foundational for the development of socioemotional competences in young children (Atzil & Gendron, 2017; Vrtička, 2017). The nature of this relationship is dyadic on multiple levels, meaning that not only verbal and nonverbal interaction between caregiver and child is bidirectional (Provenzi et al., 2018), but also their biological systems (Feldman, 2012, 2016b). Social activity between a mother and her child coordinates physiological processes and brings them in synchrony (Feldman, 2017). Extensive research in rodents has shown that maternal bodily contact and physical presence (e.g., through maternal heart rate, body heat, odor, biochemicals, hormones), as well as maternal behavior, regulate specific biological systems of the pup and appear to mediate long-term shaping effects of stress and hypertension later in life (Hofer, 1987, 1994, 1995). Following this research, biobehavioral studies in different species also demonstrated that multiple biological and behavioral systems of mother and child are connected during social contact (Champagne & Meaney, 2001; Feldman et al., 2011; Ruttle et al., 2011; Shahrokh et al., 2010). Parental biobehavioral regulation of the infant's brain and the subsequent interpersonal synchronization between parent and child may form a framework for the child's socioemotional development and maturation of the brain (Atzil & Gendron, 2017; Feldman, 2012, 2016a). Yet, due to the multifaceted nature of dyadic synchrony between parent and child, research into this matter is complex (Leclere et al., 2014).

To get insights into the neural basis of parent–child connection, studies examined parent–child interactions through behavioral observation in combination with either child "or" maternal electroencephalography (EEG) (Killeen & Teti, 2012; Liao et al., 2015) or functional near-infrared spectroscopy (fNIRS) (for review, see McDonald & Perdue, 2018). However, most of this research into adult–child connection is static, under nonnatural conditions, with the parent or child looking at a screen (e.g., see Farroni et al., 2002; Hoehl et al., 2014). These studies have provided an incredible amount of knowledge on associations between the parent–child interaction, socioemotional development, and underlying parental and child brain function, but are limited in the exploration of how synchronous neural processes support social interactions between parent and child in real-life communication.

Recently, an innovative paradigm shift from one-person neuroscience (intrapersonal) to two-person neuroscience (interpersonal) using a "dual-EEG" setup has emerged (Hari et al., 2015; Redcay & Schilbach, 2019). Dual-EEG or "EEG hyperscanning" is a method to measure brain activity signals simultaneously in multiple individuals online (Babiloni & Astolfi, 2014; Burgess, 2013; Hoehl et al., 2021; Montague et al., 2002). Parent–child dual-EEG (in short parent–child EEG), in which activity of the parental and child brain is measured simultaneously, could potentially bring insight on how parents and children are connected on a neurobiological level (Hirata et al., 2014; Noreika et al., 2020). When implemented in developmental research, this novel paradigm enables integration of concurrent neural processes with behavioral interaction online. Consequently, complementary knowledge into multimodal interpersonal synchronization between parent and child is now within reach.

This review aims to provide an overview on the upcoming field of parent–child dual-EEG and show its unique potential for future developmental studies. We focused our review on research of parents and young children (between 0 and 6 years old). Additionally, the focus of this review is on dual-EEG research, because EEG, in particular, is a noninvasive and child friendly method to study brain-to-brain synchrony during social engagement, with high temporal resolution, relatively low costs, and mobility of the system. Importantly, EEG measurement enables exploration of synchrony at the level of brain rhythms and can keep up with the speed of social interactions (with millisecond precision), as compared to the region-based synchrony of blood flow, as measured with fNIRS and functional magnetic resonance imaging (fMRI). In this review, we begin by introducing dual-EEG and the basic concepts of the different terminology. We continue by reviewing the literature on parent–child EEG by addressing the first fascinating findings of brain-to-behavior and brain-to-brain synchrony studies. We briefly touch up on some differences between parent–child EEG and parent–child fNIRS, focusing on the advantages and limitations of EEG as compared to fNIRS. We then continue by providing an overview of dual-EEG analysis techniques, including the technical challenges and solutions one may encounter. Next, we highlight the potential of parent–child EEG for developmental research by discussing novel opportunities to study healthy socioemotional development, child at risk for developing socioemotional deficits, and parent–child relational problems. Finally, we discuss potential mechanistic explanations of brain-to-brain synchrony.

2 | DUAL-EEG: DEFINING THE CONCEPT

The method of measuring brain activity from two or more brains is often termed "hyperscanning." When this measurement is performed with EEG to measure dyadic brain activity (two brains), the measurement tool can be called "dual-EEG" or "EEG-hyperscanning." The term "hyperscanning" was first coined in an fMRI study of Montague and colleagues that measured hemodynamic aspects of multiple individuals concurrently during social interactions (Montague et al., 2002). However, the first attempt to demonstrate neural relations between multiple brains using dual-EEG can be traced back to 1965. In this short report, Duane and Behrendt succeeded to "prove" that two out of 15 identical twins could extrasensory induce alpha rhythmic brain waves when separated in different rooms by eye closure of one of these twins (Duane & Behrendt, 1965). Unfortunately, but not entirely unjustified—as with many first attempts—their statistical analysis was highly criticized and their approach was forgotten for about 40 years (Babiloni & Astolfi, 2014). After many technical improvements of EEG acquisition and analysis, dual-EEG was reintroduced by several research teams (Astolfi et al., 2010; Babiloni et al., 2006; Dumas et al., 2010). Dual-EEG in combination with a behavioral or social task is increasingly used to unravel the neural underpinnings of social behavior between individuals (for review, see Burgess, 2013; Czeszumski et al., 2020; Liu et al., 2018), by linking multiple facets (i.e., neural, mental, and behavioral) of interpersonal synchrony (Hamilton, 2021).

Due to the novelty of a two-brain neuroscience and dual-EEG, there is no clear terminology for the interpersonal synchrony outcomes of a dual-EEG study yet. Different terms may refer to distinct or overlapping information on dyadic brain activity during social interaction. First of all, the terminology of the measurement method and the measure can be easily confused. The measure, in contrast to the method (i.e., dual-EEG), is the outcome of a dual-EEG study. Dual-EEG experiments are either setup to examine *brain-to-behavioral synchronization* and/or to measure *brain-to-brain synchronization* (see Figure 1). For the measure of brain synchronization, several researchers have introduced the terms "brain-to-brain synchrony," "interpersonal neural synchrony," or "interbrain connectivity," which refers to concurrent and aligned brain activity in multiple brains. From a neuroscience perspective, the term brain-to-brain synchrony fits better into the concept and terminology of parents–child synchrony than neural synchrony, because neural synchrony refers mostly to the alignment of activity of neurons in one brain. We therefore recommend brain-to-brain synchrony to be used when studying the relational processes of the parental and child brain within dual-EEG setups.

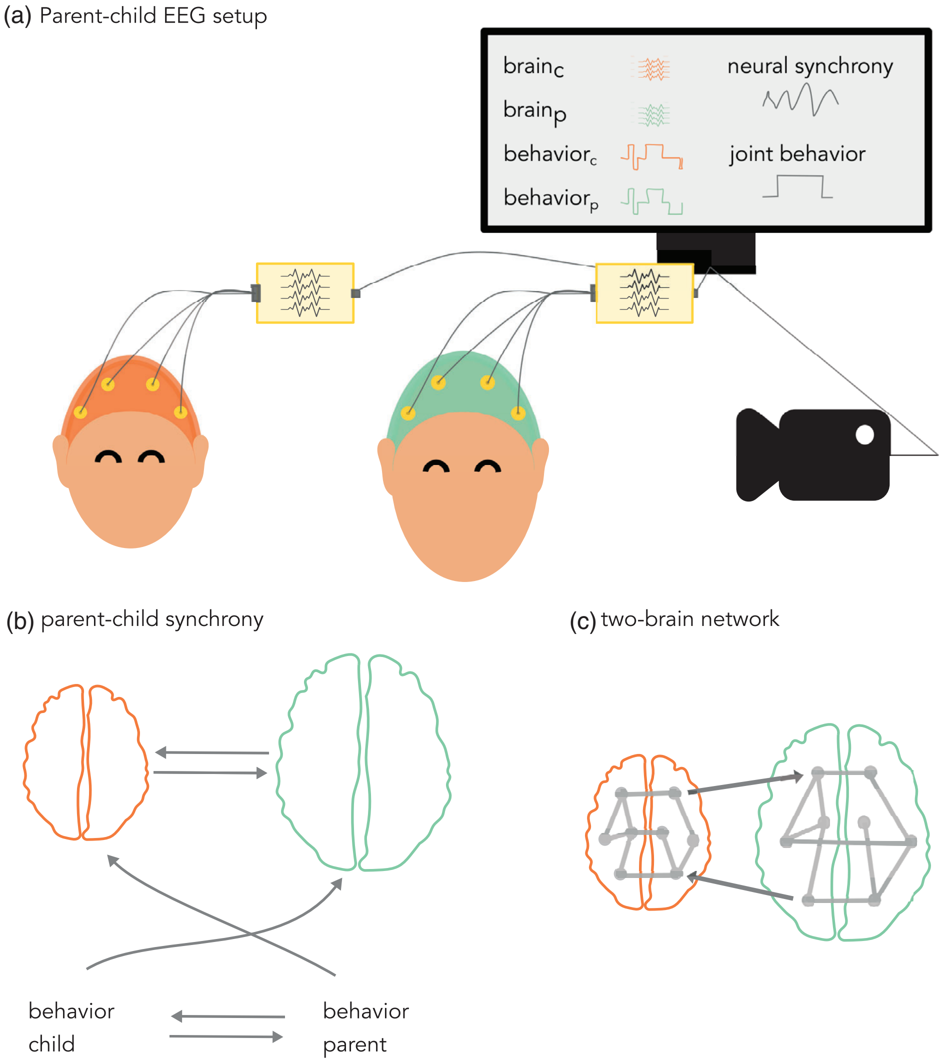


FIGURE 1 Parent–child dual electroencephalography (EEG). (a) Displayed is a simplistic view of a parent–child EEG setup, which enables the monitoring of neural and behavioral expressions during live interaction. The EEG box of the child is connected to the adult box, enabling simultaneous recordings—and sending through—of activity signals from both brains. The computer combines the EEG signals in one file, and will be able to align it to behavioral data from coded video recordings such as joint gaze or behaviorally affect. For more information about the implementation of dual-EEG setups, please see Barraza et al. (2019). (b) Displayed are possible multimodal parent–child relations that can be analyzed from a parent–child EEG setup, including behavior-to-behavior, brain-to-behavior, and brain-to-brain (associative or predictive) synchrony. (c) Displayed is a simplistic view of a brain-to-brain network that can be quantified using graph analysis in a parent–child EEG setup

In general, two kinds of social constructs are measured during dual-EEG experiments: (1) the interaction between a “sender” and “receiver” and (2) simultaneous activity to reach a common goal. In both cases, it is assumed that better social interaction or social connectedness between individuals is associated with increased brain-to-brain synchrony. Various types of brain-to-brain synchronization (e.g., phase locking, phase coherence, and Granger causality) are reported during interaction between individuals (for a recent overview, see Hoehl et al., 2021; Redcay & Schilbach, 2019), specifically between romantic partners (Djalovski et al., 2021; Kinreich et al., 2017), dyadic music performance (Sanger et al., 2012), and between strangers during a card game (Babiloni et al., 2006). Comparable relations between EEG synchrony and social behavior are seen in adolescents as well. In a study of Dikker et al. (2017), brain-to-brain synchrony of 12 students in a classroom showed to be predictive of their social engagement. Overall, these examples showed that although brains of individuals are not connected through hard-wired physical connections, various types of synchronies between two brains can be detected using dual-EEG during social interaction. Brain-to-brain synchrony could be driven by a shared sensory input, as well as internal cognitive processes supporting social interaction and communication. Moreover, the degree of social connectedness orchestrates enhanced brain-to-brain synchronization (Djalovski et al., 2021). Consequently, the association between social behavior and enhanced neural synchronization could suggest that brain-to-brain synchrony is a potential biomarker for social behavior and goals to affiliate and communicate. Although the use of neural synchrony as a biomarker is exciting and promising, we have a long road ahead of us before it can be identified as a clinically useful biomarker.

2.1 | Parent–child EEG: A brief review

Building on advances in adult dual-EEG, recent research has begun to explore naturalistic interactions between parent and child while measuring their neural activity simultaneously using a dual-EEG paradigm. Parent–child EEG may provide a framework to measure different aspects of interpersonal synchrony during rest, or during behavioral or social tasks (Figure 1a). Parent–child EEG allows to capture if and how behavioral and neural systems of a caregiver (often mother) and child are connected (either associative or predictive) during interaction (Figure 1b). In this way, parent–child EEG may bridge gaps within the theoretical biobehavioral synchrony model (Feldman, 2012), with actual neural evidence. To disentangle the multifaceted nature of dyadic synchrony between parent and child in a dual-EEG setting, we make a distinction between findings from brain-to-behavior and brain-to-brain (neural) synchrony studies in the next sections. In the final subsection, we briefly review literature from parent–child fNIRS studies and compare them with parent–child dual-EEG studies.

2.2 | Brain-to-behavior studies

In brain-to-behavior studies, the relationship between behavioral interaction and brain oscillations in either the parent or child is central. Examining behavioral and neural dynamics of parent and child deepens our understanding into "how" and "which" parent–child interactions are represented in the brain, and how they contribute to critical socioemotional development. Few dual-EEG studies examined neural–behavioral relations during different social conditions between parent and child (Atzaba-Poria et al., 2017; Krzeczkowski et al., 2020; Leong et al., 2017, 2019; Perone et al., 2020; Santamaria et al., 2020; Wass et al., 2018). These brain-to-behavioral studies examined, for instance, predicting brain activity in one dyadic member by the behavior of the other, and vice versa.

Atzaba-Poria et al. (2017) were the first to examine neurobehavioral relations in mother–child dyads using a dual-EEG setting, by measuring how positive supportive or negative nonsupportive behavior is reflected in the brain of the social partner. This study investigated whether alpha (6–9 Hz) oscillations in frontal cortex were related to behavioral correlates (Atzaba-Poria et al., 2017), because alpha balance of brain activation between frontal brain regions is related to emotional regulation during interaction (Forbes et al., 2008). In particular, they looked at asymmetry of frontal alpha between left and right hemispheres, termed frontal alpha asymmetry (FAA), in children (around 3 years of age, $N = 34$) and measured how it correlated to their mother during rest and an interactive puzzle task, while observing negative behavior of both. This study found that frontal asymmetry of the child was associated with maternal negative behavior during an interactive puzzle task, and not during rest. And vice versa, maternal frontal asymmetry was linked to negative behavior of the child during interaction. Elaborating on these findings, a recent study of Perone et al. (2020) analyzed emotion regulation and frontal alpha asymmetry of infant ($N = 10$, between 8 and 12 months old) and mother through parent–child EEG during a still-face task. This task is a hallmark emotion regulation paradigm in which a parent has to be suddenly still and expressionless (i.e., "still face") and then resume to normal interaction (i.e., "free play") with their child. During the course of the still-face task, Perone et al. found increased variability in frontal alpha asymmetry in mother and child. Specifically, they showed lower asymmetry suggesting growing negative emotions and high stress levels during the still-face period, and higher asymmetry during free play and recovery from the still-face period. Despite the small sample size, still relatively more variation in asymmetry levels was found in infants with mothers that were more responsive in general. This might be indicative for the overall relation between maternal caregiving and emotion regulation through frontal alpha asymmetry in infants. Decades of research into the link between socioemotional development and parenting already showed that supportive parental interactions with children predict positive socioemotional outcomes, whereas intrusive interactions predict negative outcomes (Keller, 2018). However, new insights into how and which parent–child interactions are represented in the brain are revealed by measuring dyadic behavioral and neural activity. Both studies indicate an important role for frontal regions and alpha power in brain-to-behavior synchrony during live emotional regulation and social communication between parent and child.

To unravel a more complete picture of parent–child brain-to-behavior synchrony, it is also interesting to look at mutual attention. In context of attention, theta band activity (3–6 Hz) might be a promising marker for social behavior in children, because increasing theta band activity in infants is associated with sustained attention (Orekhova et al., 1999) and is enhanced during naturalistic social settings (Jones et al., 2015). This approach has been adopted by a parent–child EEG study by Wass et al. (2018), showing that an increase in whole brain oscillatory theta power in infants (around 12 months of age, $N = 42$) forward predicted attentional behavior in infants during solo play, but less during joint play with one of the parents (Wass et al., 2018). These results, based on time-lagged cross-correlations, suggest that intrinsic theta neural control over attention is greater during solo play. Moreover, levels of oscillatory theta power in parents responded to changes in their infant's attention during joint play, and greater responsivity (i.e., increasing adult theta power) resulted in longer attention of the infant. The study of Wass et al. (2018) showed that neural behavior and attention are mutually predictive and confirm the overall influence of parental behavior on neural responsivity in children, and vice versa. Altogether, brain-to-behavior studies of parent–child EEG so far showed that parents and children are in synch by reacting to each other's signals not only behaviorally but also neurologically.

2.2.1 | Brain-to-brain studies

In brain-to-brain studies, the relationship between concurrent and synchronous brain oscillations between parent and child is central. Brain-to-brain synchrony could contribute to our understanding on how social interactions are represented in two brains and how it contributes to socioemotional development. For example, parent–child EEG brings the unique opportunity to associate certain interactional behaviors, such as mutual eye gaze, to brain-to-brain synchrony, in order to predict the strength of synchrony based on the characteristics of the dyadic interaction.

The relationship between multiple brains and social behavioral cues during parent–child interaction can be examined in a dual-EEG setting using a multimodal integrative approach. Social attentional cues such as affective touch, head turning, and directed gaze are thought to guide attention and learning already during early infancy (Wu & Kirkham, 2010; Wu et al., 2014), and more recently, can be linked to brain-to-brain synchrony between parent and child. For instance, a study of Leong et al. (2017) showed that directed gaze from an adult strengthened neural coupling in theta and alpha band (electrodes C3 and C4) between adult and infant (around 8 months of age, $N = 36$) brains. Additionally, infants tended to speak (vocalize) more during directed gaze, and thereby strengthening brain-to-brain synchrony with their adult partner (Leong et al., 2017). By studying the direction of synchronization between adult and infant with Granger causality, this study also provided evidence for the active role of the infant in engaging and maintaining neural synchrony with an adult partner. The influence of other social signals, such as negative and positive emotions, on brain-to-brain connectivity is also studied in recent studies (Krzeczkowski et al., 2020; Santamaria et al., 2020). Supplemental to studies that showed that maternal emotions are linked to infant frontal alpha asymmetry, and vice versa (Atzaba-Poria et al., 2017; Perone et al., 2020), Santamaria et al. showed that expression of positive emotions from the mother was associated with stronger brain-to-brain alpha connectivity (phase locking value) between mother and infant (around 10 months of age, $N = 15$) (Santamaria et al., 2020). As in adult dyads (e.g., Hasson et al., 2012; Jiang et al., 2021), these studies indicate that social signals could bring neural responses between adult and child (bidirectionally) into mutual temporal alignment. Moreover, a study of Krzeczkowski et al. showed, using an actor–partner interdependence model (APIM), that maternal frontal alpha asymmetry is predictive for infant (9 months old, $N = 29$) frontal asymmetry during happy and fear-related emotion-eliciting conditions in dyads with a high social avoiding mother (Krzeczkowski et al., 2020). They did not find an effect of infant frontal asymmetry on their mother, suggesting that mothers transfer their social avoidance behavior on to their infant and not the other way around. Parent–child EEG studies imply that oscillatory brain states in alpha and theta band of adult and child temporally align to each other to optimize social interaction or facilitate efficient communication between them.

Brain-to-brain synchronization may have additional purposes in children compared to adults. It has been hypothesized that biobehavioral synchrony between caregiver and child provides critical input for development or learning of emotions, social behavior, and attachment (Atzil & Gendron, 2017; Atzil et al., 2012; Feldman, 2016b; Feldman et al., 2011). Or even more specific, it has been suggested that parents provide rhythmical information during early social interactions, such as affective touch and singing, thereby contributing to the establishment of brain-to-brain synchrony (Markova et al., 2019; Provasi et al., 2014). One facet of this hypothesis was tested in (to date non-peer-reviewed) work from Leong et al. (2019). They showed that phase-locked brain-to-brain synchronization of alpha band between mother and infant (around 11 months of age, $N = 32$) was predictive of increased social learning of the infant. Enhanced social learning was also associated with more gaze and maternal expressions, therefore it seems to be that social learning is mediated by parental utterances and contact. Altogether, these studies in brain-to-brain coupling suggest that social signals of availability and communicative intentions such as directed gaze (Leong et al., 2017; Leong et al., 2019), readable emotions (Atzaba-Poria et al., 2017; Perone et al., 2020; Santamaria et al., 2020), affective touch, vocalization, and singing (Leong et al., 2019) are associated with brain-to-brain synchronization between caregiver and child (Wass et al., 2020), which is likely important for socioemotional learning and positive parent–child interaction.

2.2.2 | Parent–child EEG compared to fNIRS

Parent–child EEG and fNIRS are different hyperscanning approaches but supplement each other nicely (McDonald & Perdue, 2018). Parent–child fNIRS hyperscanning is an upcoming technique in the field of developmental neuroscience (for a practical implementation, see Nguyen, Hoehl, et al., 2021). fNIRS-based brain-to-brain synchrony can be measured as aligned decreases and increases of hemodynamic processes in the same brain area at roughly the same time. EEG and fNIRS have some similarities: both are noninvasive methods that enable real-life interaction and are easily usable in infants and children. There are also some key differences between the techniques. EEG conveys a direct measure of neural activity, whereas fNIRS provides an indirect measure (via blood flow) of brain activity, causing a time lag (often more than 10 s) between an event happening and showing up in the hemodynamic response (Pinti et al., 2021). EEG has better temporal resolution, enabling to keep up with the speed of social interaction, such as affective touch and gaze, with its millisecond precision (Dumas et al., 2010) and enables exploration of synchrony at the level of brain rhythms, whereas fNIRS has better spatial resolution (although both only cortex) (Lloyd-Fox et al., 2010). And lastly, although EEG facilitates the opportunity to filter out certain small movement artifacts, fNIRS has better tolerance for head movements due to its compatibility with motion sensors (Lloyd-Fox et al., 2010). These differences suggest that parent–child EEG and fNIRS are picking up different types of synchrony measurements (e.g., fast vs. slow neural responses and, spatially more general vs. specific to certain cortical regions) that are linked to different aspects of social interaction.

Parent–child fNIRS findings are in line with the EEG studies, showing enhanced brain-to-brain synchrony during natural joint interaction (Nguyen, Schleihauf, Kayhan, et al., 2021; Quinones-Camacho et al., 2020), task-based cooperation and problem-solving (Miller et al., 2019; Nguyen et al., 2020; Reindl et al., 2018; Wang et al., 2020), and joint attention (Azhari et al., 2019). Moreover, more specific spatially precise information on neural activity of important cortical regions to establish brain-to-brain synchrony can be supplemented with fNIRS research. For example, parent–child EEG points out the important role for frontal regions in relation to brain-to-behavior and brain-to-brain synchrony (Atzaba-Poria et al., 2017; Perone et al., 2020). Using the benefits of the high spatial resolution of fNIRS, adult–child fNIRS studies complement the EEG findings by showing that especially simultaneous enhanced activity of (dorsolateral and medial) prefrontal (Azhari et al., 2019; Miller et al., 2019; Nguyen et al., 2020; Nguyen, Schleihauf, Kayhan, et al., 2021; Nguyen, Schleihauf, Kungl, et al., 2021; Piazza et al., 2020; Quinones-Camacho et al., 2020; Reindl et al., 2018; Wang et al., 2020), frontal polar (Miller et al., 2019; Reindl et al., 2018), and temporal–parietal (Nguyen et al., 2020; Nguyen, Schleihauf, Kayhan, et al., 2021; Nguyen, Schleihauf, Kungl, et al., 2021) cortices can be detected during joint interaction. These studies show that fNIRS is suitable to measure and detect changes in brain-to-brain synchrony between parent and child during (long-lasting) interaction such as watching a video together, joint problem-solving, joint free play, and cooperation tasks. EEG seems to be a better fit to detect fast neural responses and rapid changing states of brain-to-brain synchrony during live parent–child interaction (Wass et al., 2020), such as mutual gaze onset and non-concurrent joint attention during free play. For example, neural fluctuations in synchrony that are linked to changes in avert and direct eye gaze can be measured using EEG (Leong et al., 2017), but are presumably too fast to pick up from the fNIRS signals. However, slower fluctuations in brain-to-brain synchrony and prolonged mutual interaction (e.g., mutual gaze and joint attention) are detectable with fNIRS and time-locked cross-correlations if the events are having a duration of multiple seconds (Piazza et al., 2020). Taken together, parent–child EEG and fNIRS measure different aspects of parent–child synchrony and therefore supplement each other and, so far, produce similar but complimentary findings.

3 | DUAL-EEG ANALYSIS TECHNIQUES

Besides the used term to refer to the observation of brain activity from two brains, the diversity of measurements to quantify the relationship between interpersonal brain activity is also extremely variable. During interpersonal “synchrony” or “entrainment,” neural, mental, and behavioral states are either concurrent (including joint action, mutual gaze, mirroring, and synchronous brain states) or sequential/predictive (including turn-taking, reciprocity, and imitation) in two individuals (Markova et al., 2019; Wass et al., 2020). No clear guidelines or standardized procedures have been developed yet to measure the various types of brain-to-brain synchronization. An overview of possible measures can be found in Box 1, including, for example, correlations, coherence, phase synchrony, and power correlations. Dealing with the multitude of possible analysis techniques to explore synchrony can be overwhelming for researchers new to the field (Noreika et al., 2020). Here, we will provide an overview of analyzing techniques from the parent–child and adult dual-EEG field that may help understand the results of dual-EEG studies and provide guidance in developing new parent–child EEG research strategies to compute parent–child connectivity.

3.1 | Coherence and correlation

Two brains could be interacting with each other in different ways; therefore, the analytic method of parent–child EEG has to be adapted to the research setting and question. One approach to measure this interaction is by looking at how correlated the signals from the two individuals are, for example, by using *Pearson's correlation* or *coherence measures* (such as *Granger causality*) (Zhang, 2018). This can be done on the clean broadband signal measured at a specific electrode (or group of electrodes), but also on time-series signals from these electrodes that are further pre-preprocessed (e.g., theta power; see Box 1). So far, correlation approaches have been used in parent–child studies (Atzaba-Poria et al., 2017; Krzeczkowski et al., 2020) to compute how behavior and brain activity covary within the dyad. Causal measures (e.g., Granger) have been used to compute the direction of influence from the adult on the child (or vice versa) (Leong et al., 2017; Samadani et al., 2021; Santamaria et al., 2020). Specifically, if one signal X (e.g., the mother EEG) influences a second signal Y (e.g., the child EEG), then trying to predict the signal Y based on a combination of X and Y's past should give better results than when trying to predict Y based on Y's past alone. If this is the case, X is “Granger causal” of Y, because it is not a true measure of causality. At the fine timescale of EEG, such instantaneous correlations may miss important interactions, and therefore cross-correlations might be a better choice when interpersonal influences during certain types of behavior or states are studied. Time-lagged *cross-correlations*, as used, for example, by the parent–child study of Wass et al. (2018), can be computed to estimate if certain (micro)behavior or neural correlate forward (or backward) predicts behavior or neural response in either child or parent.

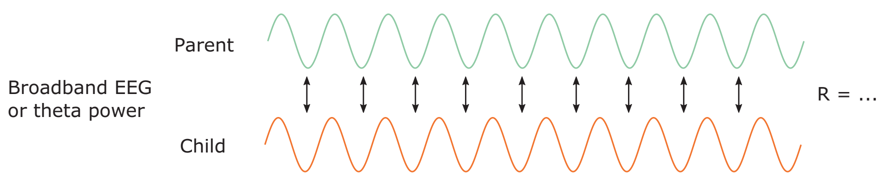
3.2 | Phase synchronization

Another method to measure brain-to-brain synchronization with dual-EEG is phase synchronization of neural oscillations (i.e., the interpersonal synchronization of oscillatory signatures). This is based on a specific hypothesis that, like intrabrain synchronization (Fries, 2005), interbrain interactions are governed by specific brain waves (frequency) operating “in-sync” (see example 3, Box 1 and Zhang, 2018). In the example, a dominant brain wave of the infant follows the brain wave of the mother (or vice versa) at a specific lag (Box 1). Phases are in synchrony if this lag is consistent over time. There are different methods of measuring this phase consistency, though the most commonly used one in parent–child studies is the *phase-locking value* (PLV) (e.g., see Leong et al., 2019; Santamaria et al., 2020). It is important to note here that there are developmental differences in the power spectrum of mother and infant (Georgieva et al., 2020). Rapid neurodevelopmental changes drive spectral shifts in EEG rhythms, with frequency peaks increasing over age (Marshall et al., 2002; Orekhova et al., 1999). For instance, alpha power has a peak frequency from 6 to 9 Hz in infants (from 5 months to 4 years of age) (Marshall et al., 2002), whereas it

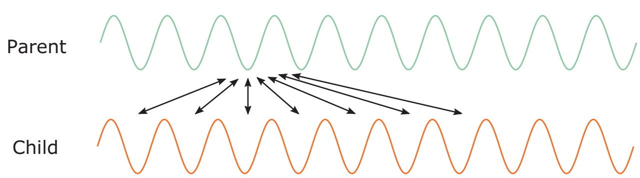
Box 1. How to measure brain-to-brain synchrony using parent-child EEG?

Different methods are available to measure the various forms of brain-to-brain synchronization:

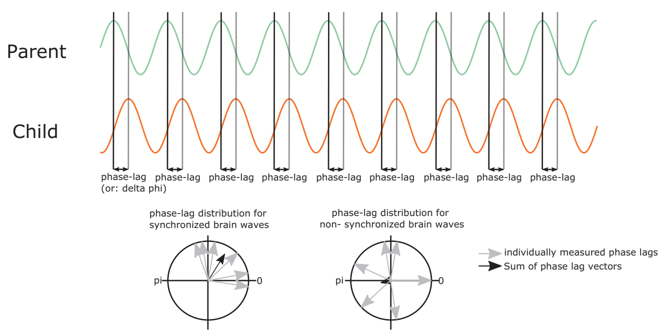
Non-directional correlations (e.g., Pearson's) provide a measure of instantaneous similarity between two signals for a given time-window and are also well-suited for measuring similarity of power traces in a specific frequency band (e.g., theta power).



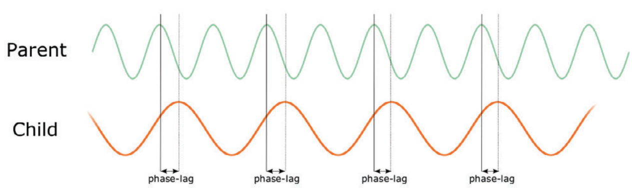
Cross-correlations between two signals also provide information on which signal is leading and at what lag. A peak in the cross-correlogram denotes at which delay the two signals interact most.
A positive delay means (in this case) the parent is leading, while a negative delay means the child is leading. If an oscillation appears in the cross correlogram the relation is rhythmic and the CCorr method needs to be applied.



Phase-locking value (PLV): Synchronization of brain waves as measured by the consistency of the phase-lag.



Cross-frequency coupling: Brain waves can also synchronize across different frequencies.



has a higher frequency in adults/mothers (9–12 Hz; Hill et al., 2020). So far, dual-EEG studies have focused mainly on the power band of the child (e.g., Leong et al., 2017; Santamaria et al., 2020). Whether analyzing synchronization with the mother's frequency as the focus provides different results is still open for investigation.

3.3 | Cross-frequency coupling

Phase–phase cross-frequency coupling (see example 4, Box 1) or *phase–amplitude cross-frequency coupling* (Canolty & Knight, 2010) would be very promising measures to overcome the problem of measuring synchronization across different dominant frequencies. Phase–phase cross-frequency is suitable to measure the quantity of phase-locking between child and mother EEG across frequencies. Phase–amplitude cross-frequency coupling could be applied to investigate if amplitudes in higher frequencies in the child are coupled to the phase of a low-frequency oscillation in the mother. Examples of these cross-frequency coupling methods are elegantly given in the work of Haresign, Phillips, Whitehorn, Goupil, et al. (2021). A problem with these coupling measures could be that those two uncoupled oscillators with a constant frequency (i.e., phase variability) would also show a highly consistent lag. Measures that specifically look at slight changes to the oscillations individually, and correlate those changes across brains, are therefore a much more robust measure of synchronization between brains.

The circular correlation (CCorr) method is such a method (Burgess, 2013). It first extracts phase shifts in the mother and child oscillations individually, and correlates these phase shifts between mother and child (see example 2 of Box 1). This provides a measure of a continuously interacting system (Burgess, 2013). Additionally, oscillation-based brain-to-brain measures can be made more sensitive by taking two other phenomena into account: variability of peak frequency and asymmetry of brain waves. First, it is common to calculate the phase or analytic amplitude of a specific brain wave by using a predetermined window of frequencies. However, it has been shown that each individual brain operates at individualized peak frequencies (Donoghue et al., 2020). Fitting the peak frequencies within a frequency range of interest could significantly improve the sensitivity of oscillation-based cross-brain interactions methods. To do such peak frequency fitting, different toolboxes have been developed (Donoghue et al., 2020; fooof toolbox). Second, common time–frequency estimation methods make the assumption that brain waves are shaped like perfect sinusoids. However, it has long been known that brain waves can be asymmetric, for example, the mu rhythm in sensorimotor cortex (Cole & Voytek, 2017). There are methods to estimate this asymmetry (Cole & Voytek, 2017), or to even extract the oscillation without forcing it into a perfect sinusoid shape (empirical mode decomposition, Quinn et al., 2021). We believe in most cases, however, the more traditional sinusoid-based methods suffice, though taking oscillation asymmetry into account could be of interest in specific cases, and as the hyperscanning field matures.

3.4 | Machine learning

Machine learning models can computationally predict (linear and non-linear) condition-specific behavior or mental states from multi-brain EEG and other multivariate data (Lemm et al., 2011; Zhang, 2018), providing a data-driven way to study mutual multivariate information between brain responses of parent and child. To date, no examples are found for machine or deep learning models in parent–child EEG research, but this might be an interesting new venue for future research, especially when you have to deal with a variety in condition-specific events (Levy et al., 2021). There are, however, clear limitations of its use; results can be hard to interpreted and these algorithms typically need a lot of data to work well (Hosseini et al., 2021), something that is often not feasible with EEG recordings in young children. However, carefully designed analyses exploiting the strengths of these algorithms could provide useful insights.

3.5 | Two-brain network

Another potential avenue for parent–child EEG research lies in the possibility to compare global brain function (i.e., compare whole brain functional connectivity patterns) between parent and child using *graph analysis*. Research of the neural "connectome" enables the analysis of global network dynamics and large samples of (potential) connections between brain regions—instead of concentrating on a single region or connection—within an individual (Sporns, 2011). Graph analysis is a technique to analyze the functional connectome and is gaining ground in pediatric research. The blueprint of the functional connectome is already developed before birth (Turk et al., 2019; van den Heuvel et al., 2015), evolves during infancy and childhood (Gao et al., 2015; Power et al., 2010), and brings a comprehensive insight into alterations of connectivity patterns and psychopathology (Di Martino et al., 2014).

Graph analysis can be used as a tool to grasp brain-to-brain connectivity between individuals concurrently (Falk & Bassett, 2017; Sanger et al., 2012; Toppi et al., 2015), for example, by seeking for the overlap of the connectome of both social partners (see Figure 1c). Higher similarity between functional connectomes of child and parent—derived from resting-state fMRI—showed to be associated with enhanced behavioral concordance and emotional competence of the child (Lee et al., 2017). Additionally, graph analysis may be a novel tool to quantify how neural information flows between partners (Falk & Bassett, 2017) or enables us to explore how a two-brain network is formed. Differences between fMRI and EEG measurements should be taken into account when reconstructing a connectome and interpreting the results. fMRI nodes in the network are usually based on an anatomical atlas and "neural activity" measures represent the blood-oxygen-level-dependent response of a specific region, whereas EEG nodes correspond with the location of the electrode and the signal represents the neural activity of all cortical (and subcortical) regions nearby. Although fMRI is the golden standard to analyze the functional connectome, EEG-based connectomes show to be highly overlapping with their fMRI counterpart and may provide new insights on neural underpinnings (Sadaghiani & Wirsich, 2020; Wirsich et al., 2020). For instance, electrophysiological data may give additional information on the temporal dynamics of brain networks (Tewarie et al., 2019).

Graph analysis might be promising to couple parent–child neural dynamics during dual-EEG measurement, especially because of the novelty and the comprehensive number of possibilities in this field. For example, a recent dual-EEG study using graph analysis shows that interbrain graph metrics (i.e., strength and degree of interpersonal functional connectivity) were higher with positive expressions of maternal emotions (Santamaria et al., 2020). Other graph metrics can be translated to a brain-to-brain connectivity model as well, for example, average shortest path length may give insight on how efficient information can be transferred from one brain to another, or identifying connector hubs may enable us to pinpoint important nodes within the two-brain network. With all these new opportunities, a first challenge will be to determine which interpersonal connectivity variables provide the most valuable information about the relationship between parent and child.

3.6 | Cautious interpretations and robustness analyses

Another important facet of parent–child EEG is to correctly interpret synchrony results (Hamilton, 2021). Cautious interpretations on interpersonal relations or cause–effect can be made using different types of sophisticated statistical models. Additionally, small variations between experimental conditions and analyses could influence the outcome. For example, the presence of another person in the experimental room, even without an explicit task, diminishes oscillatory behavior (Rolison et al., 2020). Additionally, the effect of movements—which is especially a problem in research with infants—may introduce artifacts in the EEG data (e.g., see Georgieva et al., 2020; Köster, 2016; Tal & Yuval-Greenberg, 2018), and may thereby influence power, phase estimations, and intra- and interpersonal correlations. Especially in the naturalistic settings of hyperscanning experiments, movement artifacts such as saccades (eye movements) and micro-interactions are closely linked to social interaction and thus neural epochs of interest. Eye movements towards the social partner are necessary for the onset of mutual gaze and thus for the onset of social interaction (Leong et al., 2017). As a consequence, it is almost impossible to adequately remove all motion-contaminated data from the EEG (Noreika et al., 2020), suggesting that simultaneous motion and/or facial affect are still potential drivers of "brain-to-brain synchrony" in all parent–child studies that are reviewed above. A recent EEG study in infants showed that high motion epochs are associated with more power at lower frequencies (<3 Hz) and higher frequencies (>7 Hz), but less power at theta (3–6 Hz) (Georgieva et al., 2020). The results from Georgieva et al. may implicate that synchrony between higher theta power as measured in parent–child studies (e.g., Leong et al., 2017; Wass et al., 2018) may be attributable to the specific selection of movement-free epochs. To move the field of parent–child EEG to the next level, additional sensitivity analyses such as independent component analysis (ICA) and machine learning are needed to differentiate motion from neural data as measured during parent–child EEG paradigms (Haresign, Phillips, Whitehorn, Noreika, et al., 2021).

Besides the type of recording and the problem of motion, we believe that the age of the child needs to be taken into account when interpreting the results. The shift in neural spectral characteristics (see section on analysis techniques) and behavior of the developing child have to be taken into account while interpreting the results. At a behavioral level, this means that the interpretation of the interaction (or resting state) has to be adapted to the age (or cognitive capabilities) of the child. For example, social interaction between parent and child with newborns can already focus on resting-state behavior or eye-to-eye interaction (Farroni et al., 2002), whereas older infants are already capable of cooperative interaction during play (Feldman, 2012). For sufficient neurobehavioral coupling between parent and child, it is especially important to code the EEG epoch of interest with the correct behavioral label (e.g., mutual eye contact, resting-state, cooperative playing).

3.7 | Summary

In sum, there are multiple ways to analyze dual-EEG data and there is currently no gold standard yet. Importantly, the different analyses techniques and their respective measures of synchrony often measure completely different concepts and can provide very different results (e.g., one measure may conclude perfect synchrony, whereas another computes zero synchrony). Focusing on only one method to analyze the results may therefore be a major pitfall and additional sensitivity analyses may be needed to correctly interpret the results. Consequently, we recommend that researchers explore and present multiple analyses in one publication and adapt their method to the research question. To accommodate this need for multiple analyses in dual-EEG, researchers have developed the "Hyperscanning Python Pipeline" (HyPyP), which is a comprehensive and easy open-source software package that allows to analyze different aspects of brain-to-brain synchrony (Ayrolles et al., 2021).

4 | POTENTIAL AND FUTURE DIRECTIONS FOR DEVELOPMENTAL RESEARCH

In this section, we provide an outlook of future directions in parent-child EEG that may give new perspectives on developmental biobehavioral relationships, and potentially support the community in inferring common mechanisms in different developmental social contexts, in different (clinical) populations, and their interpretations and real-life ramifications. Additionally, we provide some key outstanding questions that need to be tackled in the future (see Box 2, *Outstanding questions*). Answers to these questions will also improve the interpretation of other hyperscanning studies, because longitudinal paradigms would enable us to identify whether more synchrony between

Box 2. Outstanding questions on parent-child EEG and brain-to-brain synchrony

What measure(s) of brain-to-brain synchrony are best used in parent-child dual EEG-paradigms?

To what extend is brain-to-brain synchrony between parent and child related to dyadic interactions? What types of dyadic interactions are associated with increases or decreases in brain-to-brain synchronization?

How does the brain-to-brain synchrony pattern develop with age? Does it increase during the first years of life and become more child-driven when they become more active in their interactions with adults?

Are we able to pick up the alterations that appear in brain-to-brain synchrony patterns in children that are at higher risk to develop socioemotional problems? Are we able to detect differences when there are parental problems, such as maternal postnatal depression and anxiety?

How should we interpret brain-to-brain synchrony between a parent and a child? Is it a consequence and/or a prerequisite of social interaction? And how much of the brain-to-brain synchrony signal is actually related to simultaneous motor activity (e.g., eye-gaze) instead of synchronizing brainwaves?

parent and child is predictive of better outcomes and under which conditions.

4.1 | Potential to study healthy socioemotional development

Parent–child EEG brings the opportunity to study unique and comprehensive facets of the child's developmental change in social behavior and neural representation. We touch upon three major potencies of dual-EEG that will elevate developmental research into the social brain to a next level.

First, a major strength of parent–child EEG can be found in the coupling of brain and behavior as a tool to map socioemotional development from a more objective perspective than traditional one-person neuroscience paradigms. Psychosocial research involving infants or children may be challenging as self-report is nonexisting or limited. Using a dual-EEG approach, parent–child interaction can be studied from a more objective and quantitative perspective, because it enables the coupling between behavioral and neural synchrony during social interaction without the need of self- or parent-report (Levy et al., 2021).

Second, parent–child EEG is a paradigm that naturally enables the integration of different modalities during real-life interaction, including audio and video recordings, but also biological measurements (e.g., heart rate) that may provide information about the physiological state of both individuals during hyperscanning. Moreover, parent–child EEG in combination with other biobehavioral measures will give us a comprehensive insight on which parental and child factors are critical for interpersonal synchrony. New understandings on biobehavioral relationships may provide developmental insights into the social nature of our brain (Bell, 2020; Feldman, 2016b; Levy et al., 2021).

Third, parent–child EEG enables a comprehensive analysis of the healthy developing brain, providing the possibility to longitudinally map the evolving pattern of brain-to-behavior and brain-to-brain synchrony between parent and child. Although longitudinal research using parent–child EEG is still missing from literature, behavioral synchrony studies with a longitudinal design can already shed some light on the opportunities to study dyadic synchrony and development. For example, 10-year follow-up research shows that the interpersonal context plays a critical role in revealing how the interplay between caregiving and a child's self-regulatory skills gradually sculps emotional development over time (Feldman, 2015). Moreover, early behavioral parent–child synchrony seems to longitudinally shape the neural basis (measured by MEG) of empathy in preadolescence (Levy, Goldstein, et al., 2019) as well as mother–child neural alignment. Furthermore, early behavioral synchrony between mother and her child even predicted the neural basis of empathy (Levy et al., 2017) in mothers as measured a few years later (Levy et al., 2019a, 2019b). There is a growing need for longitudinal research in this area in order to be able to reveal new developmental perspectives: we do not know what is normal or how synchrony between parent and child develops. Quantifying the evolving pattern of parent–child synchrony will allow us to study potential consequences for the developmental outcome of the child such as variation in affection, attachment, bonding, social learning, and communication.

4.2 | Potential for the child at risk

Parent–child EEG has not yet been used as a method to examine social dynamics in clinical populations. It potentially would bring the unique opportunity to explore the neurodevelopmental trajectory of children's social brain during interaction, and to link early brain-to-brain synchrony and brain-to-behavior synchrony to later life outcomes. In this sense, altered brain-to-brain synchrony, for example, in dyads with children at risk for developing socioemotional deficits may provide a predictive value for the identification of later life social deficits (Levy, Goldstein, et al., 2019).

Research suggests that intraneural functional connectivity patterns are modified by the accumulation of socioemotional experiences (Gabard-Durnam et al., 2016). Studying objective physiological measures of parent–child interactions could lead to the identification of children at risk for socioemotional deficits and further knowledge on sensitive windows of socioemotional development. Autism spectrum disorder, for example, may be detected by disturbances in behavioral and neural synchrony between individuals. Using a dual-fMRI paradigm in adult pairs (around 25 years of age) with neurotypical individuals and individuals at the high-functioning end of the autism spectrum, studies showed that an autistic individual showed diminished inter-brain coherence and altered visual processing of gaze (Tanabe et al., 2012) and altered intraneural connectivity and brain-to-brain synchronization with their partner (Salmi et al., 2013). It therefore seems that brains of individuals with high-functioning autism indeed synchronize less with others.

Little is known about altered dyadic synchrony (dyssynchronization) in the developing child with autism spectrum disorder or other neurodevelopmental disorders. No dual-EEG studies have tackled this paradigm yet. One of the reasons may be that there are limits to certain age groups participating. For example, many diagnoses of infants with neurodevelopmental are clear at a later age and bringing a young child with social and/or mental difficulties to the lab may be challenging or undesirable for the parents. Few promising studies (dual-MEG and fNIRS) examined dyssynchronization between parent and child, providing valuable information for setting up a parent–child EEG paradigm exploring synchronization between parent and child at risk. For example, pilot results (n = 8) in a dual-MEG study during face-to-face interaction between mother and child with autism spectrum disorder (around 6 years of age) indicated that diminished behavioral and neural synchrony between mother and child can be detected (Hasegawa et al., 2016). A recent fNIRS study showed no parent–child (children between 8 and 18 years) group differences on brain-to-brain synchrony (only behavioral) between typically developing children and children with autism spectrum disorder (Kruppa et al., 2020). However, they found that the strength of brain-to-brain synchrony during competition and cooperation between parents and their typically developing children was modulated (respectively, higher synchrony and lower synchrony with parents) by the age of the child, whereas this effect was not detected in the group of children with autism spectrum disorder. Moreover, synchrony differences may be mediated by the severity of autism symptoms as indicated by a recent fNIRS study, which performed hyperscanning in mother and child with autism spectrum disorder (Wang et al., 2020). Together, these studies provide new understandings on neurodevelopmental disorders, but sometimes show contradictory findings and thereby highlight the complexity of detecting synchrony differences on an individual level.

Longitudinal research into parent–child interactions and dual-EEG could supplement these findings from related scientific fields, by closely monitoring synchrony at the level of brain rhythms at the speed of different social interactions. This highlights the need of parent–child EEG in revealing the underpinnings of disorders of social functioning (Leong & Schilbach, 2019). Autism is just one example; yet, research into other neurodevelopmental disorders, childhood psychiatry, and social dysfunction, such as childhood (social) anxiety, is only at the very early beginnings.

4.3 | Potential for parental problems

Parent–child EEG may also help to understand relational difficulties and differences within parent–child interaction by providing an objective tool to disentangle neurobehavioral correlates. For example, a recent parent–child EEG study shows that a musical intervention in nonspeaking children with severe physical disabilities (e.g., cerebral palsy) can enhance brain-to-brain coupling with their parent (Samadani et al., 2021), using brain-to-brain synchrony as a marker to measure cognitive–emotional coupling between parent and child. Research into parental differences in a dual-EEG setting is limited, and therefore brings new directions to explore in future research. We touch upon a few dual-EEG and fNIRS studies that may provide some guidance in the implementation of parenting behavior in the parent–child research setup.

As a start, future parent–child EEG research can explore how parenting, mediated by sex differences, for example, influences brain-to-brain synchrony. Most research on parent–child interactions focus on mothers (Bell, 2020), whereas differences between father–child and mother–child interactions could provide new insights into relational differences between mothers and fathers (Feldman, 2003). To date, parent–child EEG is only performed between biological mother and child (not sex specific), thereby missing the opportunity to explore possible differences between social roles of mothers, fathers, and nonbiological caregivers and differences between daughters and sons. A first glimpse into parental roles and sex differences suggests that fNIRS-based brain-to-brain synchrony differences are found by comparing mother–daughter and mother–son interactions, showing increased synchrony during cooperation between mother and son as compared to mother and daughter (Miller et al., 2019). Moreover, a father–child fNIRS study observed enhanced brain-to-brain synchrony in prefrontal and temporo-parietal regions between father and child during cooperative problem-solving compared to individual problem-solving (Nguyen, Schleihauf, Kungl, et al., 2021). This study also showed that the father's attitude toward parenting—using a self-report questionnaire—was positively associated with enhanced brain-to-brain synchrony (Nguyen, Schleihauf, Kungl, et al., 2021), suggesting that the perceived level of commitment of taking care of a child matters for the level of brain-to-brain synchrony. Differences in micro-behaviors and neural sensitivity to infant cues may be the drivers of individual differences in parent–child brain-to-brain synchrony between dyads. Due to limited empirical evidence, future parent–child EEG research may reveal new insights on parenting roles, sex differences, and brain-to-brain synchrony and interaction.

Besides sex differences, parental mental health is of major importance for child socioemotional development. For example, parent–child EEG already showed that expression of positive emotions from the mother was associated with more frontal alpha asymmetry (Atzaba-Poria et al., 2017; Perone et al., 2020) and showing stronger brain-to-brain alpha connectivity between mother and infant (Santamaria et al., 2020). The other way around, diminished fNIRS-based brain-to-brain synchrony between mother and child (4–5 years old) showed to be associated with longer periods of the child's irritability after a frustrating period (Quinones-Camacho et al., 2020). It would be interesting to investigate the influence of parental behaviors related to symptoms of a mood and anxiety disorder on brain-to-brain synchrony. Still, parent–child EEG studies including parental trauma, anxiety, and depression are still missing from literature. From previous research, we hypothesize that these parameters could influence brain development by changing interpersonal synchrony between parent and child. For example, a mother–child fNIRS study shows that parental stress is associated with poor dyadic co-regulation based on altered brain-to-brain synchrony (Azhari et al., 2019). Additionally, maternal depression is associated with altered attachment and child oscillatory rhythms during childhood (Pratt et al., 2019) and altered frontal asymmetry during infancy (Dawson et al., 1999; Field et al., 2001; Hill et al., 2020; Wen et al., 2017). These examples suggest that parental parameters could influence brain development by changing interpersonal synchrony between parent and child, but this hypothesis needs to be investigated further in future research.

4.4 | Mechanistic explanation of brain-to-brain synchrony

A final key avenue for future research is to unravel the underlying mechanisms and biological basis of neural synchrony findings. Despite the recent developments in parent–child EEG, it is difficult to determine a common or complete neural mechanism that underpins dyadic synchrony in the parenting context, due to the limited amount and the heterogeneity of studies that have been published so far in this field. It is still unclear what parent–child synchrony means, and whether it causally facilitates social interaction or social learning, here termed the "*causality issue*". Despite sophisticated statistical models and validation, it remains difficult to determine cause and effect of synchronic interactions. For example, brain-to-brain synchrony could be driven by behavioral coordination and shared sensory input, as well as in the absence of behavioral coordination by temporally co-occurring brain activity underlying internal cognitive processes supporting social interaction and communication (Hamilton, 2021; Wass et al., 2020). Moreover, even if synchrony is not solely attributable to shared environmental input, it may be a factor that increases the amount of synchrony (Burgess, 2013; Hoehl et al., 2021). Related to this issue, one can confuse comparable brain activity in two individuals with interpersonal neural synchrony, for example, when they are presented with similar stimuli. It has been shown, for instance, that false interpersonal connections arose between pseudo-pairs from different people independently measured, but under the same experimental conditions (Burgess, 2013). In parent–child studies, it could be that joint attention toward, for instance, a toy, results in similar brain activation in both mother and child, which could be interpreted as brain-to-brain synchrony. Future efforts and theoretical work should focus on solving the causality issue of brain-to-brain synchrony.

On way to overcome the causality issue is to supplement our knowledge on the neural underpinnings of dyadic synchrony by animal models and invasive research. For example, an upcoming method to study the causality of interpersonal synchronization on social interaction can be found in the combination of EEG hyperscanning and brain stimulation (Novembre & Iannetti, 2021). Being able to link neural stimulation to activity in another individual brings the causal underpinnings of two-brain neuroscience within reach. Also, a study of frontal cortex activity in bats showed that neural activity (measured by local field potentials) in this region enters into a highly correlated state when animals share a social environment, which cannot simply be explained by nonsocial factors such as shared sensory input or behavioral patterns (Zhang & Yartsev, 2019). This correlated brain state was present when animals were simply in the same room, and increased when they interacted behaviorally. Although this study shows that shared social environments induce highly coordinated brain states across animals, the exact mechanism supporting brains to be "in sync" remains an open question. Translating this to a developmental design, we believe that interpersonal synchrony between parent and child seems to be a dynamical system, where it is a consequence and a prerequisite of social exchange and interaction. Taken together, a clear understanding of the underlying basis of brain-to-brain synchrony and novel comprehensive statistical and methodological validations may hold the key to move the field of parent–child EEG forward.

5 | CONCLUDING REMARKS

Parent–child EEG research is a new field that emerged a couple of years ago and already showed spectacular new insights into parent–child interaction and child socioemotional development. Moreover, it brings the opportunity of integrating neural and behavioral data, showing that parent and child are in synchrony on multiple levels. We have learned that behavioral and neural systems of a caregiver (often mother) and child seem to be in synchrony during interaction, showing concurrent coordination of neural, mental, and behavioral processes to facilitate interpersonal transmission of information, and likely forming the basis for socioemotional learning and development. Research so far revealed that infants are already active interaction partners and not merely passive in interacting with another person, engaging and maintaining brain-to-brain synchrony with their parent (or other adult). Parent–child EEG brings several opportunities such as studying the two-brain network or to get precious parenting information despite the lack of child report. Additionally, this novel paradigm is promising in the field of the developing brain, providing a comprehensive framework to map and reveal the neural underpinnings of typical and atypical socioemotional development over time. The analysis of multiple EEG data is technical and challenging, but when performed well, parent–child EEG brings the unique opportunity to provide new predictive values for the identification of later life social deficits and may also help to understand relational difficulties and differences within the parent–child relationship.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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