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RESEARCH ARTICLE

Visualizing the invisible tie: Linking parent–child neural synchrony to parents' and children's attachment representations

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Abstract

It is a central tenet of attachment theory that individual differences in attachment representations organize behavior during social interactions. Secure attachment representations also facilitate behavioral synchrony, a key component of adaptive parent–child interactions. Yet, the dynamic neural processes underlying these interactions and the potential role of attachment representations remain largely unknown. A growing body of research indicates that interpersonal neural synchrony (INS) could be a potential neurobiological correlate of high interaction and relationship quality. In this study, we examined whether interpersonal neural and behavioral synchrony during parent–child interaction is associated with parent and child attachment representations. In total, 140 parents (74 mothers and 66 fathers) and their children (age 5–6 years; 60 girls and 80 boys) engaged in cooperative versus individual problem-solving. INS in frontal and temporal regions was assessed with functional near-infrared spectroscopy hyperscanning. Attachment representations were ascertained by means of the Adult Attachment Interview in parents and a story-completion task in children, alongside video-coded behavioral synchrony. Findings revealed increased INS during cooperative versus individual problem solving across all dyads ($X^2(2) = 9.37$, $p = 0.009$). Remarkably, individual differences in attachment representations were associated with INS but not behavioral synchrony ($p > 0.159$) during cooperation. More specifically, insecure maternal attachment representations were related to higher mother–child INS in frontal regions ($X^2(3) = 9.18$, $p = 0.027$). Conversely, secure daughter attachment representations were related to higher daughter–parent INS within temporal regions ($X^2(3) = 12.58$, $p = 0.006$). Our data thus provide further indication for INS as a promising correlate to probe the neurobiological underpinnings of attachment representations in the context of early parent–child interactions.

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attachment, fNIRS, hyperscanning, Interpersonal neural synchrony (INS), parent–child interaction, synchrony

Research Highlights

- We assessed attachment representations using narrative measures and interpersonal neural synchrony (INS) during parent-child problem-solving.
- Dyads including mothers with insecure attachment representations showed higher INS in left prefrontal regions.
- Dyads including daughters with secure attachment representations showed higher INS in right temporo-parietal regions.
- INS is a promising correlate to probe the neurobiological underpinnings of attachment representations in the context of parent-child interactions, especially within the mutual prediction framework.

1 | INTRODUCTION

Harry Harlow's work in rhesus monkeys on "The Nature of Love" (Harlow, 1958) paved the way to a new understanding of the mechanisms by which infants become attached to their mothers. Emphasizing the tight interplay between attachment and caregiving, Harlow highlighted the existence of an attachment relationship beyond the readily apparent maternal function of sustenance provision. Attachment theorists have since built on the idea of an "invisible" affectional tie that binds children with their parents throughout the lifespan and underscored the role of parent–child interaction quality as a vehicle for the developing attachment relationship (Ainsworth et al., 1978; Bowlby, 1982). By the preschool years, this relationship becomes more balanced, with both parent and child contributing to dyadic interaction quality that evolves to be more collaborative. A promising new line of research has emerged over the last decade to capture this inherently interactive process, leveraging interpersonal behavioral and particularly interpersonal neural synchrony (INS). This research connects INS during parent-child interaction to interaction behavior and relationship quality (Nguyen, Schleihauf, et al., 2020; Nguyen, Schleihauf, Kungl, et al., 2021). The present study is the first to examine the links between INS and both parents' and children's attachment representations. Notably, attachment theorists generated complex measures to assess attachment representations in terms of individuals' ability to create coherent narratives around their attachment experiences. Following this narrative approach, we used an interview-based gold-standard measure of attachment in parents and a developmentally appropriate counterpart in their preschool-aged children

2 | PARENT–CHILD INTERACTION FROM AN ATTACHMENT PERSPECTIVE

Attachment theory provides a comprehensive framework for understanding human social and emotional development through the lens of early attachment relationships (Bowlby, 1982). Parent–child relationships comprise several functions, including the primary evolutionary goals of sustenance and protection. In addition, they set the context for cognitive growth by providing the child with the stimulation and structure needed to develop complex concepts about the world. Bowlby further viewed the parent–child relationship as a critical source of emotion co-regulation. With major developmental achievements during the early years, children become increasingly capable of finding more flexible ways to seek reassurance from attachment figures and engage with them in a collaborative manner. In doing so, the primary goal of the attachment relationship changes from proximity to availability (Bosmans & Kerns, 2015). The parent–child relationship evolves into what Bowlby (1982) referred to as a "goal-corrected partnership"—that is, parents and children increasingly share the task of coordination between each other's perspectives and goals (Marvin et al., 2016). This progressively equal partnership can be observed in more structured tasks like problem-solving, which is especially pertinent to preschoolers. Indeed, research on problem-solving interactions highlights that both parent and child contribute to interaction quality and thus to children's growth of competence (see Colman & Thompson, 2002).

2.1 | Synchrony as a measure of dyadic processes

A longstanding line of behavioral research has shown that interpersonal synchrony is one powerful correlate of parent-child interaction quality (Feldman, 2007). Interpersonal synchrony describes the give and take in social exchanges and is conceptualized as the temporal relationship between parents' and children's social behavior. Importantly, interpersonal synchrony emerges early in ontogeny and is thought to represent a critical experience that underlies our capacity to successfully navigate and coordinate complex social situations (Markova & Nguyen, 2023).

Previous evidence highlights how interpersonal synchrony shapes children's attachment development. For example, synchronous interaction, indexed by shared positive affect, predominates in parent-toddler dyads where children were classified as securely (versus insecurely) attached in the Strange Situation Procedure (Lindsey & Caldera, 2015). Children from mother-infant dyads characterized by well-timed, reciprocal interactions are also more likely to develop secure attachments than those with disproportionately asynchronous exchange patterns (Isabella & Belsky, 1991). Yet, children's attachment representations at preschool age—shaped by repeated interaction experiences—also affect dyadic parent-child interactions as children grow older (e.g., Becker-Stoll et al., 2008). Here, our study adopts a new approach, asking whether attachment representations at the individual level coincide with interpersonal synchrony during problem-solving within the parent-preschooler dyad.

Importantly extending considerations of interpersonal synchrony in the behavioral domain, synchrony can nowadays also be assessed through the measurement of simultaneous brain activity (i.e., *hyperscanning)*. This novel approach provides a crucial and otherwise inaccessible layer of empirical evidence regarding neural processes involved in interpersonal interactions beyond behavioral interaction quality. Such INS has been shown to emerge during mutually engaged and reciprocal interactions over the lifespan, and more specifically when interactants exchange behavioral and physiological signals through the environment (Babiloni & Astolfi, 2014; Czeszumski et al., 2020; Dumas et al., 2011; Hasson et al., 2012; Hoehl et al., 2021; Nguyen, Bánki, et al., 2020). From both a theoretical and a meta-analytical perspective, the dorsolateral prefrontal cortex (dlPFC) and the temporo-parietal junction (TPJ) have been identified as two central brain areas relevant to INS (e.g., Czeszumski et al., 2020; Gvirts & Perlmutter, 2020; Hoehl et al., 2021; Redcay & Schilbach, 2019). More precisely, the TPJ is part of an extended neural network involved in mentalizing and making inferences about other people's mental states (e.g., Koster-Hale & Saxe, 2013; Saxe & Wexler, 2005), while the PFC plays an important role in processes related to prediction and attention (e.g., Gvirts & Perlmutter, 2020, Raz & Saxe, 2020).

Recent theoretical frameworks have characterized INS in terms of a mutual prediction account. This account links increases in INS to situations within which interacting individuals mutually predict their own as well as others' actions and intentions (Dumas et al., 2011; Friston & Frith, 2015; Hoehl et al., 2021; Kingsbury et al., 2019). This account furthermore suggests that temporal regularity of communicative behaviors and their subjective socio-emotional weighting facilitates mutual predictions (Hoehl et al., 2021; Markova et al., 2019; Wass et al., 2020).

While empirical work in this area is still in its infancy, integrating INS with attachment research is both timely and carries much theoretical appeal, given that mutual prediction may play a fundamental role in the formation and maintenance of individual differences in attachment (Long et al., 2020; White et al., 2020, 2023). Thus, as the parties involved in the attachment relationship increasingly "get to know" each other, they also progressively engage in predicting what their partner will think and do. Furthermore, these predictions will be based on internal representations derived from previous interaction experiences with one another (Thompson, 2016). At the individual level, neurophysiological concomitants of expectancy (violation) have proven robust correlates of variations in attachment and their generalization to new encounters across development (e.g., White et al., 2013, 2021). INS, in turn, holds the promise of providing access to how individual differences in interpersonal expectations play out at the dyadic level. Indeed, recent studies on INS during parent-child interaction offer some first indications for its relevance to variations across different behavioral interaction patterns, such as behavioral synchrony, turn-taking, affectionate touch, and affect attunement (Nguyen, Abney, et al., 2021; Nguyen, Schleihauf, et al., 2020; Nguyen, Schleihauf, Kayhan, et al., 2021; Quiñones-Camacho et al., 2020; Santamaria et al., 2020). Importantly, these behavioral patterns can differ between mothers and fathers (e.g., Teufl & Ahnert, 2022). Previous studies have touched upon differences in the topographical distribution of INS across the dlPFC and TPJ as well as in the extent of INS-behavior correlations (Nguyen, Schleihauf, Kungl, et al., 2021). However, no studies, to date, have performed any direct statistical tests pertaining to parental biological sex. Taken together, these considerations corroborate the need to examine further individual differences in attachment quality (taking biological sex into consideration) to better understand how parents and children get "in sync" and how this relates to their emerging attachment relationship.

2.2 | Mutual prediction and internal working models of attachment

In line with the aforementioned mutual prediction account, the present study aimed to clarify the role of internal working models (IWMs) of attachment in relation to INS during parent-child interaction. IWMs are theorized to originate from early interaction experiences and to serve as an underlying organizational structure that guides individuals' current social information processing (Dykas & Cassidy, 2011). In other words, IWMs constitute internalized mental representations of the self and others that give rise to more generalized expectations as a key regulatory mechanism underlying behavior in social situations (Thompson, 2016; Thompson et al., 2022).

The structure of IWMs consists of multiple organizational levels that emerge during consecutive developmental periods. While in the early years, IWMs are assessed on the procedural level reflected in infants' behavior toward their caregiver, they become organized on a higher level of mental representation as children grow older (Spangler & Zimmermann, 1999). The current study employed narrative measures of attachment, that is, the Adult Attachment Interview (AAI, George et al., 1985) and a story-completion measure (Emde et al., 2003) in children, following the gold-standard approach to assessing IWMs at the level of representations from preschool-age onward (e.g., Bretherton et al., 1990). More precisely, we assumed that in both children and adults, mental representations of attachment are reflected in their ability to provide a coherent narrative—for example, when probed to recall their attachment history (AAI) or complete attachment-relevant story beginnings (Hesse, 2016; Main et al., 1985). Notably, verbal responses to these probes are viewed in terms of how well they meet the criteria of the "cooperative principle" (Grice, 1989), that is, quality, quantity, relevance, and manner, resulting in a comprehensible narrative for the interviewer. Thus, compared to questionnaires, narrative measures involve an inherently dyadic approach to the assessment of IWMs. At the empirical level, besides the mother's actual support during the interaction, individual differences in infants' early attachment were found to be predictive of 6-year-olds' ability to make use of co-regulation during mother–child problem solving (Geserick & Spangler, 2007). In contrast, preschoolers classified as insecure displayed more negative emotions like frustration and anger during collaborative problem solving with their mothers (Colman & Thompson, 2002). Notably, these studies assessed children's attachment security based on their behavior within the mother-child dyad. On the level of mental representations, attachment derived from narratives has been linked to children's socio-affective cue processing (Kungl et al., 2023) and social competence (Veríssimo et al., 2014) as well as adolescents' behavior during interaction with their mothers (Becker-Stoll et al., 2008) and unfamiliar others (Feeney et al., 2008).

On the parents' side, children's attachment behavior is thought to activate a complementary caregiving system that is embedded in how parents recall experiences with their own primary caregivers. Accordingly, parents' attachment representations predict parenting behavior and may, therefore, also affect the quality of parent–child interactions (van IJzendoorn, 1995). Various studies employing the AAI have found that mothers' state of mind regarding attachment is predictive of their neural processing of infant emotional cues (Leyh et al., 2016; Lowell et al., 2023; Slade et al., 2005) and that parents classified as secure in the AAI are more likely to accurately perceive their offspring's emotional signals and respond in a prompt and adequate manner during free-play as well as during instructed interactions (McFarland-Piazza et al., 2012; van IJzendoorn, 1995).

To summarize, mutual expectations between interaction partners may be viewed as the vehicle that drives dyadic processes where both parent and child adapt to each other based on previous interaction experiences. In this view, both partners' attachment representations, including expectations of the self and the other's behavior (i.e., IWMs), may specifically relate to measures of dyadic processes.

2.3 | The current study

The current study examined whether parents' and children's attachment representations (assessed by the AAI and story-completions, respectively) are associated with INS and behavioral synchrony during parent–child interaction. First, we tested both mothers and fathers and their preschool-aged children in a cooperative versus individual problem-solving task. We expected higher parent-child INS in frontal and temporal brain areas during cooperation than the individual condition. Second, we investigated the role of parental attachment representations with the AAI. We predicted higher parent-child INS and behavioral synchrony for dyads including parents classified as secure versus insecure in their attachment representations. Third, we investigated the role of children's attachment representations with story-completions. We predicted coherence (indicative of secure attachment representations in children) to positively correlate with parent-child INS and behavioral synchrony. When testing the above three hypotheses, we always took the brain regions of interest as well as parents' and children's biological sex into account.

3 | METHODS

3.1 | Sample description

One-hundred forty parents (74 mothers; $M = 38.10$ years, $SD = 4.63$ years) and their biologically related preschool children (60 girls; $M = 5.33$ years, $SD = 0.29$ years) participated in the present study. Out of the initially recruited 147 dyads, seven were excluded due to non-compliance or technical issues (see Supplementary Materials S1 for further information). Due to the COVID-19 pandemic, the AAI could only be administered to a reduced number of parents, resulting in a sample of $N = 119$ for analyses relating INS with behavioral synchrony to parent attachment representations. Also, story completions could only be administered to $N = 89$ children with dyadic INS data in the current sample. The study was approved by the ethics committee of the Medical Faculty of the University of Leipzig (No. 138/18-ek). For more information regarding statistical power, a priori sample size considerations, and demographic sample characteristics, please refer to Supplementary Materials S1 and Table S4).

3.2 | Procedure

During the experiment, each parent-child dyad was seated face-to-face, separated by a table, and guided through a cooperative problem-solving condition (120 s), an individual problem-solving condition (120 s), and 80 s of rest with eyes closed in between each condition (see Figure 1). Cooperation and individual problem-solving were repeated twice, and the order was counterbalanced. In the problem-solving conditions, the parent and child were instructed to either cooperatively or individually arrange tangram puzzles with seven geometric shapes and recreate templates of abstract forms, objects, and animals (see Nguyen, Schleihauf et al. (2020) for more information). During the individual condition, an opaque screen was put in between the dyad to help the parent and the child to focus on their own puzzle. In the resting phases, the parent and child were instructed to close their eyes, relax, and refrain from talking to each other. Subsequently, the child had to solve a preschool form (not reported here). The whole procedure was recorded on video from three different angles, capturing the parent, the child, and the dyad, respectively. In the current study, video and fNIRS data were temporally linked using the instruction of the experimenters timed to a manually sent trigger (using custom code) to determine the start of each condition. Thus, the video recordings were segmented according to the verbal instruction, while the fNIRS was segmented according to the manual trigger.

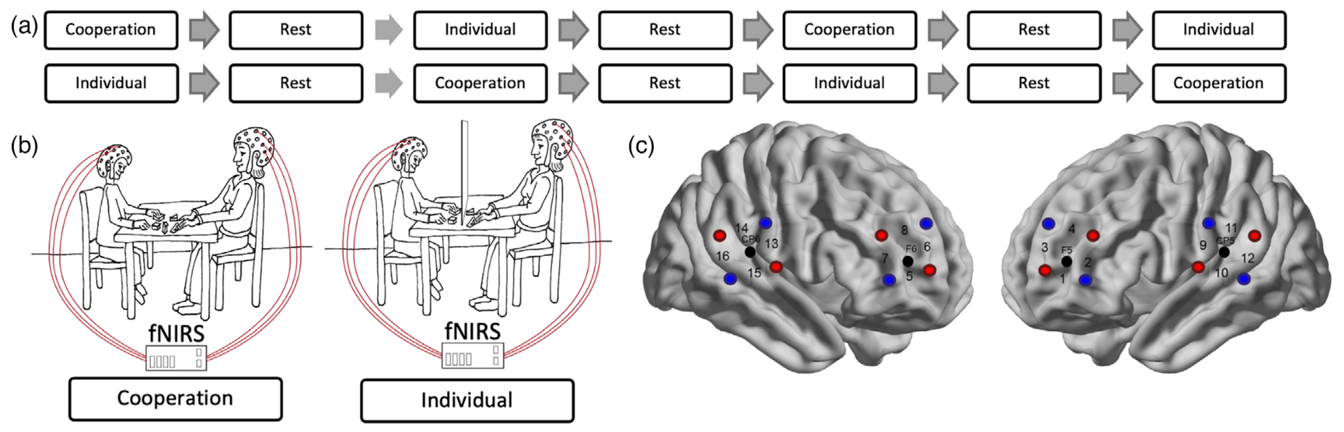

FIGURE 1 Schematic outline of the current study and optode configurations of fNIRS measurements. (a and b) Parent–child dyads participated in cooperative (120 s) and individual problem solving (120 s) with 80 s of rest interlaced, while their brain activities were measured using fNIRS (red lines indicate fiber cables). The order of cooperation and individual problem solving were counterbalanced, resulting in two sequences. (c) Throughout the experiment, the brain activity of parent and child was measured by 16 channels located over the left and right dorsolateral prefrontal cortex (dlPFC; Brodmann area 46) and temporo-parietal junction (TPJ; Brodmann area 39/40), respectively, resulting in four ROIs.

3.3 | Measures

3.3.1 | Interpersonal neural synchrony (INS)

fNIRS. We recorded oxyhemoglobin (HbO) and deoxyhemoglobin (HbR) concentration changes in children and parents using a NIRScout 16 × 16 system (NIRx Medizintechnik GmbH, Germany). For each participant, eight light sources and eight detectors were grouped into four 2 × 2 probe sets and attached to an EEG cap with a 10–20 configuration (easycap). The probe sets resulted in 16 measurement channels with equal between-optode distances of 3 cm. Probes assessing brain activity in the left and right dorsolateral prefrontal cortex (dlPFC) surrounded electrode locations for F5 and F6, whereas the probes over the left and right temporo-parietal junction (TPJ) were placed according to CP5 and CP6. These regions of interest (ROI) were based on previous studies investigating cooperative parent-child interactions (Nguyen, Schleihauf et al., 2020; Reindl et al., 2018). The absorption of near-infrared light was measured at the wavelengths of 760 and 850 nm, and the sampling frequency was 7.8125 Hz.

fNIRS processing. fNIRS data were preprocessed according to a freely available hyperscanning analysis guide for parent-child interactions (Nguyen, Hoehl, et al., 2021). We used MATLAB-based functions derived from SPM for fNIRS (Tak et al., 2016) and homer2 (Huppert et al., 2009). Raw data were first converted into optical density and automatically pruned using the function *enprunechannels* (dRange = [0.02–2.5], SNR-Threshold = 10). As a result of this procedure, in addition to the visual heart-band check, the mean number of excluded channels was 0.52 (*SD* = 1.057, *range* = 0–4) per dyad. Raw optical density data were motion-corrected using a spline interpolation algorithm (MARA). The approach comprised a smoothing procedure based on local regression using weighted linear least squares and a 2nd-degree polynomial model (Scholkmann et al., 2010). The motion-corrected data was then filtered with a band-pass parameter of 0.01–0.5 Hz (Nguyen, Hoehl, et al., 2021). Next, the filtered data were converted to HbO and HbR values based on modified Beer-Lambert Law with age-dependent differential path length factors. In the following statistical analyses, we focused on HbO values, which were reported to be more sensitive to changes in the regional cerebral blood flow (Hoshi, 2016). Statistical analyses for HbR are included in Supplementary Materials (S2).

Wavelet Transform Coherence (WTC). INS was estimated using Wavelet Transform Coherence (WTC) based on the Morlet wavelet (Chang & Glover, 2010; Grinsted et al., 2004). WTC estimates a coherence coefficient between two fNIRS time series based on frequency and time and thus results in a synchrony score comprising both in-phase, phase-lagged, and antiphase synchrony within a certain frequency band. Recent studies highlight the importance of task-relevant frequencies (Kayhan et al., 2022; Molina-Rodríguez et al., 2022), which in the current study—based on previous studies using the same paradigm (Nguyen, Schleihauf, et al., 2020; Nguyen, Schleihauf, Kungl, et al., 2021)—was around 30 s. However, we knew from previous work that there is a high variability in the task frequency between parent-child dyads, with some dyads being considerably faster than others. Furthermore, there was no way for us to control for this variance extrinsically as we wanted to preserve the naturalistic nature of the task. Therefore, we chose a wider frequency range within which we performed our WTC analysis to account for this naturally occurring variance. The frequency band of interest for this study was thus determined to be 10–50 period seconds (approx. 0.02–0.1 Hz). WTC values were averaged across conditions and frequency bands, resulting in 16 (channels) × 3 (conditions) INS values. For all three conditions, the same data length, namely 240 s, went into the calculation. We further conducted a random pair analysis with 19,460 permutations to rule out effects due to spurious correlation. To do so, each time series from a given child was paired with the corresponding time series of every parent other than their own (i.e., 139 times), resulting in a distribution of "random pair" WTC values. These values were then averaged for each channel and child; thus, each "true" WTC value had a "random" equivalent.

3.4 | Behavioral synchrony

Behavioral synchrony was rated from the video recordings by two trained research assistants in terms of behavioral reciprocity. Behavioral synchrony was derived using a customized coding scheme based on the Coding System for Mother–Child Interactions (CSMCI, Healey et al., 2010). Behavioral synchrony was rated as high when the dyad showed contingent behavioral responses to the interaction partner, mutual engagement, and enjoyment in the interaction. Lower ratings of behavioral synchrony indicated passive interactions and intrusiveness (for further details, see Supplementary Materials S10). The scale was rated on a 7-point Likert-type scale (1 = no occurrence, 7 = continuous occurrence) and averaged over the two cooperation conditions. Any discrepancy of more than one point on each scale between coders was reviewed, and a consensus was obtained. Inter-rater reliability was calculated on 25% of the included dyads, resulting in an intraclass coefficient in the good range (ICC = 0.770), indicating high agreement between raters.

3.5 | Adult attachment interview (AAI)

Parental attachment representations were assessed using the German translation of the Adult Attachment Interview (AAI, George et al., 1985; Gloger-Tippelt, 2011). The AAI is a widely used semistructured interview consisting of 18 questions targeting the evaluation of parents' early experiences with their own primary caregivers (mostly both parents), as well as experiences of separation and significant losses. It further asks individuals to reflect on how their relationship with their primary caregivers has changed over the years and what they have learned from their experiences, especially regarding their own parent role. The AAI's reliability and validity are well-established (for a review, see Hesse, 2008). Postgraduate students conducted interviews after receiving extensive training and transcribed verbatim. Two certified coders, who had already reached good agreement in previous studies, coded the transcripts using the scoring and classification manual provided by Main, Goldwyn, and Hesse (2002). Consistent with the organizational view, individuals were assigned to one of three organized classifications (secure, insecure-dismissing, or insecure-preoccupied) representing differences in attachment quality (Steele & Steele, 2021), that is, use of certain strategies to manage affect and cognition throughout the interview. According to the manual, classifications are based on the evaluation of transcripts regarding mental states around attachment-related experiences, that is, idealization, derogation of attachment, as well as current anger and passivity of speech, and finally, levels of narrative coherence and cooperation (Grice, 2002). Coders further double-coded ten randomly selected transcripts from the current study, reaching 80% agreement, Cohen's kappa = 0.68. Analyses were performed using the 2-way classification (secure vs. insecure) and the 3-way classification (secure, insecure-dismissing, insecure-preoccupied reported in Supplementary Materials S3).

3.6 | Picture story stem battery (PSSB)

We used a novel adaptation of the traditional story-completion approach—a valid and reliable narrative measure of internal attachment-related representations of 3- to 8-year-olds (Emde et al., 2003; Yuval-Adler & Oppenheim, 2015). To this end, children were asked to complete four widely used standardized and scripted stories beginnings ("Hot Gravy," "Fear in the Dark," "Scooter," "Scary Dog"; see Emde et al., 2003; Hill et al., 2007). These "story-stems" were selected, given that they involved (1) the child protagonist facing a distressing/ threatening scenario (e.g., injury, fear), thought to activate the attachment system and (2) available parent figures standing nearby to provide a potential secure base/safe haven for the child protagonist. To scaffold comprehension of each stem, we additionally developed a picture of the core threatening scenario, with the help of a children's book illustrator. Following other picture-based narrative attachment measures (George & West, 2001), facial expressions of characters in the pictures were omitted to avert inadvertently biasing the child towards a certain interpretation of the story stem via visible emotional cues in the picture. Analogous to the AAI and as a widely accepted index of more secure attachment-related representations, we focused on Hill et al.'s (2009) 12-point coherence scale, which assesses the child's narrative in terms of its fluency, sequential fit with and logical elaboration of the stem as well as the resolution of the problem presented therein. Previous findings on the coherence scale support its intraindividual 1-year stability at preschool age ($r = 0.50$; Oppenheim et al., 1997), as well as associations with infant attachment security (Sher-Censor & Oppenheim, 2004) and parental coherence (Sher-Censor et al., 2013). Adding to this evidence base, in the present sample, we also found that preschoolers with a secure (vs insecure) parent showed higher narrative coherence, with a moderate effect size (White et al., in preparation). For more information, please see Supplementary Materials (S4) and White et al. 2014. Inter-rater reliability was calculated on 16% of the dyads with PSSBs, resulting in an intraclass coefficient in the good range (ICC = 0.775).

3.7 | Statistical analysis

All statistical analyses were conducted in RStudio (R Studio Team, 2021) using generalized linear mixed-effects (GLME) modeling using packages glmmTMB (Brooks et al., 2017) and emmeans (Lenth, 2019). Using GLME allowed us to model the dependent variable using a beta distribution (bound by 0 and 1) and accounting for nesting within the data (i.e., channel within ROI in condition within dyads) as well as missing data. The final model thus created an estimated average of four channels as the estimate of each ROI. We ran one analysis for INS and one for behavioral synchrony with condition (cooperation, individual—and initially also rest; see below), region of interest (bilateral dlPFC, bilateral TPJ), parental attachment classification from the AAI (secure, insecure), children's PSSB coherence scores, parents' and children's biological sex (male, female), and/or pairing (true, random) as fixed factors where appropriate and dyads as random intercepts. For more information, please refer to the Supplementary Materials (S5).

4 | RESULTS

Descriptive data on parental and children's attachment representations, behavioral synchrony, and PSSB coherence scores (including sex differences) can be found in Supplementary Materials (S6). Links between INS and behavioral synchrony during cooperation are reported in Supplementary Materials (S7).

4.1 | INS during parent-child problem solving

In an initial control analysis, we tested whether INS was enhanced in true compared to random pairs in bilateral dlPFC and TPJ during the cooperation condition compared to the individual condition and rest ($N = 140$). The model output showed a significant main effect of condition, $X^2(2) = 176.21$, $p < 0.001$, a significant main effect of true versus random pairs, $X^2(2) = 1157.02$, $p < 0.001$, and a significant interaction between condition and true versus random pairs, $X^2(2) = 69.73$, $p < 0.001$. All other tested effects remained nonsignificant, $p > 0.236$. Subsequent posthoc contrasts between true and random pairs in the three conditions revealed that true (versus random) pairs showed higher INS across all ROIs in the cooperation condition: true pairs: *emmeans* = 0.322, *SE* = 0.001, 95% CI = [0.319, 0.325]; random pairs: *emmeans* = 0.298, *SE* = 0.001, 95% CI = [0.296, 0.299], OR = 1.12. True and random pairs also significantly differed in INS during the other two conditions—individual condition: true pairs: *emmeans* = 0.310, *SE* = 0.001, 95% CI = [0.308, 0.312]; random pairs: *emmeans* = 0.297, *SE* = 0.001, 95% CI = [0.295, 0.298], OR = 1.07, rest condition: true pairs: *emmeans* = 0.312, *SE* = 0.001, 95% CI = [0.310, 0.314]; random pairs: *emmeans* = 0.288, *SE* = 0.001, 95% CI = [0.286, 0.290], OR = 1.12 (see Supplementary Materials Figure S2). Consequently, we continued our statistical analyses regarding INS within all four ROIs in true pairs only (see Nguyen, Schleihauf, Kungl, et al., 2021). In doing so, we focused on the cooperation condition only when specifically examining associations with parents' and children's attachment representations.

4.2 | INS and parental attachment representations

In the following analyses in true pairs pertaining to parental attachment representations, we only considered INS during the cooperation condition, which was then related to a secure versus insecure two-way classification of parents' attachment representations derived from the AAI ($N = 119$) as well as parental biological sex. The model output revealed a significant main effect of parental biological sex, $X^2(1) = 36.21$, $p < 0.001$, and a significant interaction effect between ROI, parental biological sex, and parents' two-way attachment representations, $X^2(3) = 9.18$, $p = 0.027$ (Figure 2). In the following, we report posthoc analyses of the main effect and highest-order interaction between ROI, parental biological sex, and parents' two-way attachment representations (Figure 2). First, father–child dyads showed higher INS within all ROIs (*emmeans* = 0.328, *SE* = 0.002, 95% CI = [0.324, 0.332]) than mother-child dyads (*emmeans* = 0.306, *SE* = 0.002, 95% CI = [0.302, 0.310]), OR = 0.892. Next, we compared INS within the four ROIs during cooperation as a function of parents' two-way attachment representations by splitting the data into mother–child and father–child dyads. This posthoc analysis revealed that during the cooperation condition, dyads in which mothers had insecure attachment representations showed higher INS in the left dlPFC, *emmeans* = 0.312, *SE* = 0.005, 95% CI = [0.302, 0.322], than dyads in which mothers had secure attachment representations, *emmeans* = 0.303, *SE* = 0.004, 95% CI = [0.295, 0.310], OR = 1.092. INS during cooperation did not differ as a function of mothers' attachment representations in any of the other three ROIs, $p > 0.134$, and INS during cooperation did not differ as a function of fathers' attachment representations in any of the four ROIs, $p > 0.130$, either.

There were no significant associations between INS during cooperation in any ROIs and parental biological sex and parents' attachment when using three-way attachment representations (secure, insecure-dismissing, insecure-preoccupied); for further details, see Supplementary Materials (S3).

4.3 | Secondary analysis of INS and parental biological sex

Due to the significant main effect of parental biological sex in the previous mixed-effects model comprising attachment representations, we further tested whether INS differed between mother–child and father–child dyads irrespective of attachment representations. Here, we also included the additional factor condition (cooperation, individual). The model output revealed significant main effects of condition, $X^2(2) = 72.52$, $p < 0.001$ (see Supplementary Materials Figure S2), and parental biological sex, $X^2(1) = 63.34$, $p < 0.001$, as well as significant interactions between condition and parental biological sex, $X^2(2) = 18.64$, $p < 0.001$, and condition, ROI and parental biological sex, $X^2(6) = 13.38$, $p = 0.026$ (Figure 3). For a complete account of posthoc analyses regarding all main effects and interactions, please refer to Supplementary Materials (S8). In the following, we only report posthoc analyses of the highest-order interaction between condition, ROI, and parental biological sex.

First, we compared INS within the four ROIs between conditions by splitting the data into mother-child and father-child dyads. This analysis revealed that mother-child dyads only showed significantly higher INS during the cooperation (versus the individual) condition in the left dlPFC, *emmeans* = 0.051, *SE* = 0.021, 95% CI = [0.001, 0.101], OR = 1.05, and in the right TPJ, *emmeans* = 0.063, *SE* = 0.019, 95% CI = [0.019, 0.107], OR = 1.07. Father–child dyads showed significantly

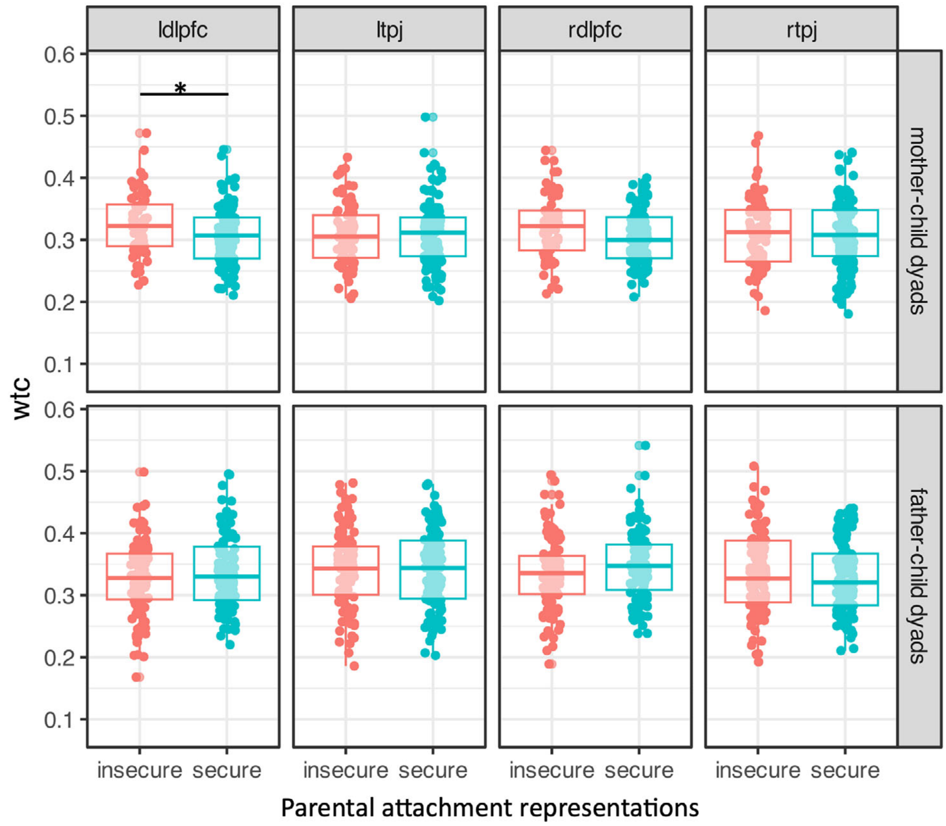

FIGURE 2 Comparing INS in ROIs in relation to parental attachment representations in mother–child and father–child dyads. ROI denomination in columns: ldlpfc, left dorsolateral prefrontal cortex; ltpj, left temporoparietal junction; rdlpfc, right dorsolateral prefrontal cortex; rtpj, right, temporoparietal junction; parental biological sex in rows: mother–child dyads on the top, father–child dyads on the bottom row. Wavelet transforms coherence (wtc) on the y-axis and parents' two-way AAI attachment representations in different shadings, that is, insecure in red, secure in blue, on the x-Axis. **p* < 0.050.

higher INS during the cooperation (versus the individual) condition in the left dlPFC, *emmeans* = 0.006, *SE* = 0.020, 95% CI = [0.022, 0.115], OR = 1.07, right dlPFC, *emmeans* = 0.102, *SE* = 0.020, 95% CI = [0.057, 0.147], OR = 1.11, and left TPJ, *emmeans* = 0.085, *SE* = 0.020, 95% CI = [0.040, 0.130], OR = 1.09. Importantly, the difference in INS between the cooperation and the individual condition in the right dlPFC and left TPJ was stronger in father-child dyads than in mother–child dyads (right dlPFC: $t(525) = -2.155$, $p = 0.032$, *Cohen's d* = 0.347; left TPJ: $t(588) = -3.159$, $p = 0.002$, $d = 0.227$; left dlPFC & right TPJ: $p > 0.472$).

4.4 | Behavioral synchrony and parental attachment representations

Next, we examined the relation between behavioral synchrony, parental two-way AAI attachment representations, and parental biological sex. As for the previous analysis with a main focus on attachment, we only did so for the cooperation condition. The model thus included the main and interaction effects of parental attachment representations and parental biological sex. We found a significant fixed effect of parental biological sex, $X^2(1) = 23.34$, $p < 0.001$, $d = 18.9$. Mothers showed higher behavioral synchrony with their children (*emmeans* = 5.320, *SE* = 0.241, 95% CI = [4.840, 5.800]) than fathers (*emmeans* = 3.750, *SE* = 0.235, 95% CI = [3.280, 4.220]). None of the other effects were significant, $p > 0.159$. Thus, we found no significant relation between parent–child behavioral synchrony and parental attachment representations.

4.5 | INS and children's attachment representations

We also examined the role of children's attachment representations for INS ($N = 89$). Here, we included PSSB coherence as a fixed effect in addition to ROI and children's biological sex, and INS was included as the response variable. Again, as this analysis mainly focused on attachment, we only considered the cooperation condition. The model outputs showed a significant interaction effect of ROI, children's biological sex, and PSSB coherence, $X^2(3) = 12.58$, $p = 0.006$. All other fixed and interaction effects were nonsignificant, $p > 0.107$. In posthoc analyses, we found that specifically parent–daughter dyads showed a positive correlation between INS in the rTPJ and daughters' PSSB coherence scores, *trend* = 0.028, *SE* = 0.013, 95% CI = [0.002, 0.054],

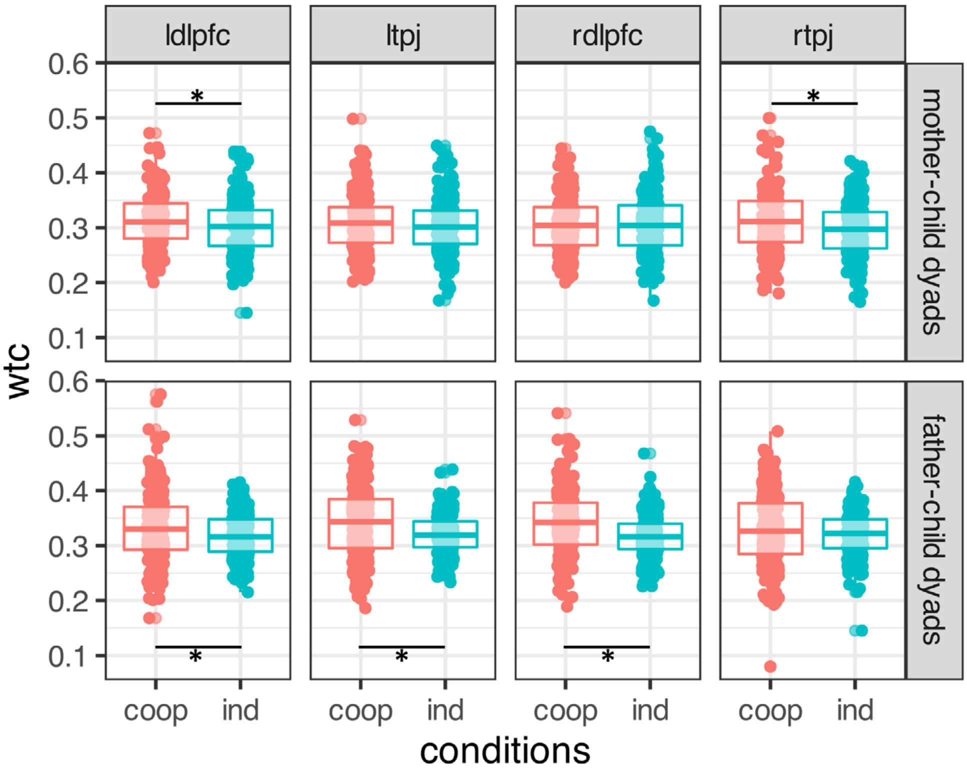

FIGURE 3 Comparing INS in ROIs between conditions in mother–child and father–child dyads. ROI denomination in columns: ldlpfc, left dorsolateral prefrontal cortex; ltpj, left temporoparietal junction; rdlpfc, right dorsolateral prefrontal cortex; rtpj, right, temporoparietal junction; parental biological sex in rows: mother–child dyads on the top, father–child dyads on the bottom row. INS values were estimated using wavelet transform coherence (wtc) on the y-axis and conditions in different shadings, that is, cooperation (coop) in red, and individual (ind) in blue, on the x-axis. $^*p < 0.050$.

d = 0.085 (Figure 4). None of the other parent–child dyad and ROI combinations showed a significant relation between INS and children's attachment representations.

4.6 | Behavioral synchrony and children's attachment representations

We also examined the association between children's PSSB coherence, behavioral synchrony, and children's biological sex. However, none of these relations were significant, $p > 0.803$.

Finally, we also tested a potential interaction effect between parental and children's attachment representations in relation to INS. None of these analyses revealed any significant effects—details are available in Supplementary Materials (S9).

5 | DISCUSSION

In the current study, we set out to investigate the relationship between INS, behavioral synchrony, and parental and children's attachment representations. Our results showed that both mothers and fathers displayed increased INS with their children during collaborative (versus individual) problem-solving. We also observed associations between INS—but not behavioral synchrony—and parental and children's attachment representations. On the one hand, while mothers with insecure (versus secure) attachment representations derived from the AAI showed higher INS with their children during collaboration in the left dlPFC, no links between INS during collaboration and fathers' attachment representations were present. Interestingly, our secondary analyses revealed that topographical INS patterns also differed between dyads, with father–child (as compared to mother–child) dyads showing significantly stronger INS during collaboration in right dlPFC and left TPJ. On the other hand, there was a positive correlation between daughters' attachment security indexed by PSSB coherence scores and INS with their parents during collaboration in the right TPJ. We discuss these results in relation to current attachment research and theory, particularly how internal representations of close relationships can potentially help explain variance in parent–child INS.

5.1 | INS during parent–child problem-solving

Our results showed significantly increased parent-child INS during collaborative (versus individual) problem-solving in frontal and temporal brain regions for dyads comprising both mothers and fathers. Both the dlPFC and TPJ have been associated with a variety of socio-cognitive processes (i.e., shared attention and intention, joint decision-making,

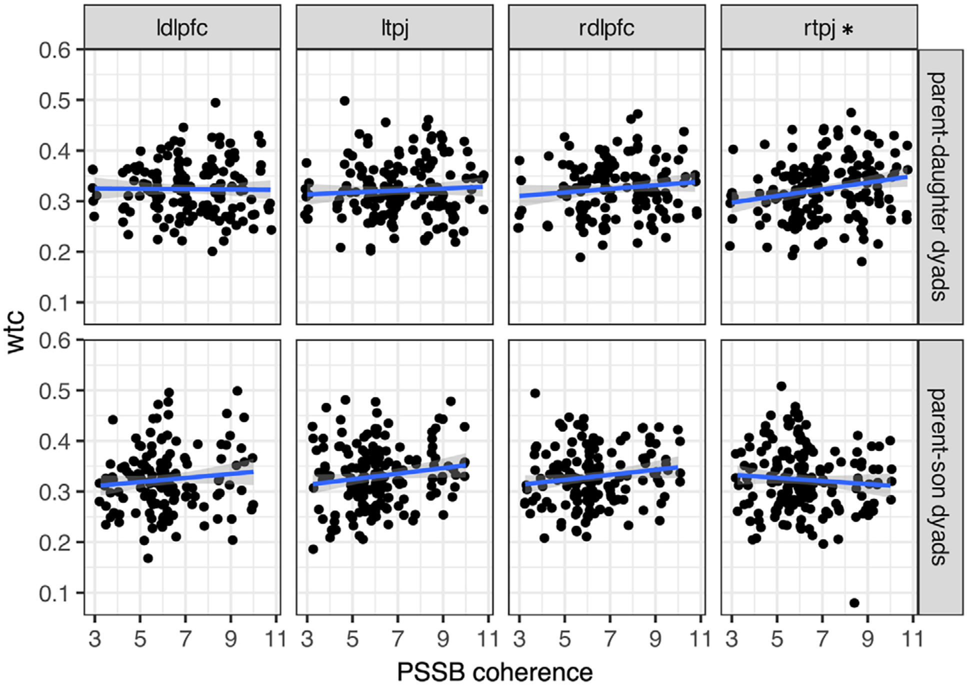

FIGURE 4 The association between INS and children's attachment representations in parent-daughter and parent-son dyads. ROI denomination in columns: ldlpfc, left dorsolateral prefrontal cortex; ltpj, left temporoparietal junction; rdlpfc, right dorsolateral prefrontal cortex; rtpj, right, temporoparietal junction; children's biological sex in rows: parent–daughter dyads on the top, parent–son dyads on the bottom row. Wavelet transform coherence (wtc) on the y-Axis, children's Picture Story Stem Battery (PSSB) coherence on the x-Axis. *$p < 0.050$.

mutual prediction, and mentalizing) and are thought to be particularly involved in INS (Czeszumski et al., 2020; Gvirts & Perlmutter, 2020; Hoehl et al., 2021; Lotter et al., 2023; Raz & Saxe, 2020; Redcay & Schilbach, 2019). We previously reported increased mother–child INS during collaborative problem-solving in the same areas within a different sample of mother-child dyads (Nguyen, Schleihauf, et al., 2020). Therefore, the present pattern of findings represents an important (partial) replication. The current study, however, allowed us to delve into the individual and dyadic differences of dyads in relation to INS. In particular, attachment representations of both parents and children are suggested to be related to mutual predictions in social interactions. In turn, mutual predictions might be reflected in the level of INS in interacting dyads (Kingsbury et al., 2019).

5.2 | INS, behavioral synchrony, and parental attachment representations

Social interactions can be influenced by interactants' previous interaction experiences like those encoded in attachment representations (Thompson, 2016). In the present study, we found evidence for the interplay between both parental and children's attachment representations and INS, but not behavioral synchrony, during cooperation. Regarding parental attachment representations, we observed a significant interaction between parent–child INS during cooperation and ROI, parental biological sex, and parental two-way attachment representations (i.e., secure vs. insecure) derived from the AAI. As the only significant posthoc test emerging from this interaction, our results showed that dyads comprising mothers with insecure (versus secure) attachment representations displayed higher INS with their children during cooperation in the left dlPFC. Although father-child dyads visually displayed the opposite (i.e., secure vs. insecure) INS pattern in the left dlPFC, this posthoc difference did not reach significance as such. Furthermore, no significant posthoc differences in INS pertaining to parental attachment representations were present in the three other ROIs when analyzed separately for mother- and father–child dyads.

INS in the PFC has previously been associated with neural computational processes of attention coordination and co-regulation during social interactions (Grossmann, 2013; Gvirts & Perlmutter, 2020; Redcay & Schilbach, 2019). Finding an association between INS in (left) dlPFC and maternal attachment representations may thus tentatively point to a role of INS in relation to the previously proposed attachment and caregiving neural systems by which parents' own attachment representations may translate into future caregiving behavior toward their children (Canterberry & Gillath, 2012; George & Solomon, 1996, 1999; Psouni, 2019; Simpson & Rholes, 2000).

Interestingly, we found that dyads in which mothers had insecure (versus secure) attachment representations showed increased mother–child INS during cooperation, but no significant differences in behavioral synchrony. Insecure attachment representations comprise secondary strategies of hyperactivation in preoccupied and deactivation in dismissing individuals (e.g., Mikulincer et al., 2009). Along these lines, our results may support the "optimum midrange model" (Beebe &

McCrorie, 2010), postulating the presence of an "adequate" amount of synchrony, with "too little" or "too much" synchrony potentially being linked to interaction and relationship difficulties. Pertaining to attachment theory, more preoccupied attachment may be associated with "too much" synchrony. At the same time, more dismissing attachments might feed into the "too little" range for optimal child development. In support of this assumption, previous evidence suggests both heightened and lowered behavioral contingencies to represent efforts to adapt to a stressful situation (Beebe et al., 2011). In particular, heightened contingencies and potentially evocative behaviors (Hajal & Paley, 2020) might facilitate mutual prediction of one's own and other's actions, which could be reflected in increased dyadic INS. Importantly, during the course of early attachment development, children come to anticipate their parents' responses to their own distress and acquire strategies to deal with them adaptively. For example, children who have experienced inconsistent or less responsive caregiving—more likely to be displayed by insecurely attached parents—learn to make an effort to become attuned and adjust their behavior when interacting with that specific type of parent (Benoit, 2004; van IJzendoorn & Bakermans-Kranenburg, 2019). Thus, dyads with insecure (as compared to secure) mothers may be characterized by excessive efforts to coordinate and attend as well as mutually predict the course of interactions with their offspring, which could potentially yield increased dyadic INS in the dlPFC. On the other hand, children with securely attached mothers are likely to have internalized them as a secure base that facilitates a more flexible interaction in which the mother leads by "being there when you need me" instead of being "always on" (see Smith et al., 2021), promoting more self-reliance at this developmental stage. However, more work in larger samples is needed to differentiate between insecure-preoccupied versus insecure-dismissive parental attachment, in combination with different parent–child biological sex combinations, which will eventually yield more specific conclusions.

Interestingly, while mothers' and fathers' attachment representations were previously found to relate to parental caregiving representations (Psouni, 2019), we only found maternal but not paternal attachment representations to be significantly associated with parent–child INS during cooperation in the current sample. One potential explanation may be the lifetime-associated impact of motherhood on cognition and the brain (Orchard et al., 2023). Conversely, father–child interactions may be more strongly affected by how involved fathers are in child rearing (Brown et al., 2012; Giannotti et al., 2022; Lamb, 2010). Higher paternal involvement and associated caregiving beliefs seem to be not only related to intraindividual differences in fathers' brain structure (Abraham & Feldman, 2022; Horstman et al., 2022; Long et al., 2021) but also to interpersonal neural dynamics, including father–child INS (Azhari et al., 2021; Nguyen, Schleihauf, Kungl, et al., 2021). Taken together, such findings point to the relevance of various father-specific factors that can be associated with paternal brain anatomy and function, INS, behavioral synchrony, and behavior besides paternal attachment representations.

Further sex differences emerged in our secondary analyses. More precisely, we found that INS during cooperation (versus individual problem-solving) was stronger in father–child than in mother–child dyads. One possible interpretation for such parental biological sex differences in INS could be related to behavioral synchrony. Exploratory analyses showed that behavioral synchrony was not only significantly enhanced in mother-child as compared to father-child dyads (see Supplementary Materials [S6]), but also only significantly correlated with INS in mother- but not father-child dyads in previous studies (Nguyen, Schleihauf, et al., 2020; Nguyen, Schleihauf, Kungl, et al., 2021). We thus surmise that increased INS during cooperation in father-child dyads could relate to compensatory mechanisms to overcome the relative lack of behavioral synchrony. We could furthermore speculate that it may be generally more difficult for fathers to behaviorally synchronize with their children during cooperative problem-solving because such tasks might be less familiar to them than to mothers. Previous research on father–child interactions highlights that fathers seem to engage more in active play with their children, such as rough and tumble, instead of more structured and cognitively demanding games, which are more often performed by mother–child dyads (e.g., Fletcher et al., 2013; Teufl et al., 2020). Further studies are needed to elucidate the role of parental biological sex more firmly in parent–child interaction, also in association with INS.

Notably, our findings of increased neural synchrony in father–child (as compared to mother–child) dyads, as well as in dyads with insecure (as compared to secure) mothers, challenge a simplified view of increased INS reflecting higher relationship quality. We suggest that, for example, increased INS may, in some cases, indicate a compensatory mechanism that facilitates interaction at the behavioral level. Still, our findings do not allow for causal interpretations or generalizations but stress the need to take context and individual differences into account when looking at differences in INS.

5.3 | INS, behavioral synchrony, and children's attachment representations

Similar to parental attachment representations, we also found evidence for a significant association between children's attachment representations and parent-child INS, but not behavioral synchrony. Specifically, we observed a significant interaction between INS during cooperation and ROI, children's biological sex, and children's attachment security indexed by PSSB coherence. Subsequent posthoc tests revealed that, specifically in daughter-parent dyads (as compared to parent-son dyads), there was a positive correlation between PSSB coherence scores and INS during cooperation in the rTPJ. Behavioral synchrony, however, did not differ regarding children's attachment representations or children's biological sex.

Interestingly, the TPJ as part of a neural network involved in mentalizing processes (Koster-Hale & Saxe, 2013; Saxe & Wexler, 2005) appears to be particularly relevant for encoding live and dynamic social interactions from a second-person perspective (Decety & Lamm, 2007; Hoehl et al., 2021; Santiesteban et al., 2015). Notably, increased INS in the TPJ was not evidenced when interaction partners were asked to make explicit predictions about each other but rather emerged in direct interaction and, thus, during ongoing implicit mutual prediction (Kayhan et al., 2022). As we did not have any specific hypothesis regarding the link between INS and children's attachment representations as a function of children's biological sex, we can only speculate about the observed pattern of associations. One possible explanation may be related to the presence of sex differences in attachment representations and mentalizing abilities at preschool age, with girls generally showing higher coherence scores (Gloger-Tippelt & Kappler, 2016; Pierrehumbert et al., 2009) and higher mentalizing abilities than boys (Keulers et al., 2010; Poznyak et al., 2019). In line with such evidence, we observed that girls' coherence scores were higher than those of boys overall within the present sample (see exploratory analyses in Supplementary Materials [S6]).

Studies that more generally explain sex differences in attachment may also help to clarify our finding of increased INS in dyads including more securely attached girls. Accordingly, sex differences in attachment narratives may partially result from different socialization patterns and conversational styles within the family (see Di Folco et al., 2017). Previous evidence suggests that girls generally elicit different behaviors in parents than boys (van Polanen et al., 2017). Parents engage in more elaborative talk with their daughters than sons, which promotes a better understanding of self and others (Fivush, 2011). This dyadic pattern may contribute to daughters' ability to present more coherent narratives (Fivush et al., 2000) and, simultaneously, more mutual understanding, as reflected in increased daughter-parent INS. Moreover, supporting this assumption, mother-child dyads including securely attached girls were found to elaborate on negative and positive topics more often than dyads with insecure girls (Farrar et al., 1997). In this line, elaboration in the context of social discourse has been defined as "one of the avenues through which IWMs are developmentally constructed and revised" (Thompson et al., 2022, p. 5).

Our results concord with the idea that parent–child dyads involving preschool-aged daughters with more secure attachment representations (as compared to parent–son dyads) might engage and align more in mutually predictive processes during interactions with their parents as indexed by increased INS in the rTPJ. This finding may be indicative of a "secure pattern" in parent-daughter dyads that resulted from specific previous interaction experiences of the dyad: in general, securely attached children are known to have experienced more continuously available and reliably responsive parents (Isabella, 1993). In such a safe environment, children can freely navigate the social world, including others' minds (Fonagy & Luyten, 2018). Consequently, representations of secure attachment in children are also linked to understanding others' emotions and beliefs (Zeegers et al., 2019), which is fundamental to the formation of goal-corrected partnerships in the preschool years. Further, dyads with securely attached children identify by elaborative discourse, which facilitates understanding of others' inner states as children grow (Ontai & Thompson, 2002). In dyads with more securely attached daughters, increased dyadic INS in the rTPJ may thus reflect a history of a well-attuned child-parent relationship in times when children depended on the parents' continuous contingent responses in which both partners have come to develop a sense of predictability of the other's behavior and mental states. This may particularly apply to parent-daughter dyads, presumably distinguishing themselves by previous experiences of more elaborative talk and exchange about inner states (as compared to parent-son dyads), which in turn could be especially relevant when investigating narrative coherence in relation to INS.

Finally, we did not find behavioral synchrony to be associated with children's biological sex and attachment representations derived from the PSSB. Interestingly, previous evidence suggests a link between attachment security and other attachment-relevant behaviors, that is, less unnecessary help-seeking, fewer inability attributions, and more metacognitive strategies during problem solving (Colman & Thompson, 2002; Moss & Gosselin, 1997). Indeed, secure attachment representations reflect an internalization of experiences that, by this developmental stage, enables children to anticipate parents' reassurance and—given this sense of security/predictability—act more self-reliant in tackling the task on their own. Future studies could further test additional attachment-related behaviors in association with INS to understand the complex interplay between attachment representations, INS, and interaction behavior.

In sum, it may come as a surprise that we found higher INS to be associated with both more insecure attachment representations (among mother–child dyads) and more secure attachment representations (among parent–daughter dyads), respectively. However, it is important to note that these findings occurred in two functionally distinct regions (i.e., in the dlPFC vs. the rTPJ) not only thought to subserve differing socio-cognitive processes but also distinctively linked to individual differences in attachment (Long et al., 2020; White et al., 2023). In addition, despite certain commonalities, attachment representations in children and parents differ in important ways. Parental attachment representations are defined as the way parents recall their own caregiving history. Thus, they are more complex and potentially affected by new experiences like the transition to parenthood, which may even evoke a reorganization process (Crowell & Waters, 2005). Parental attachment representations may also be viewed as resulting from the parents' effort to come to terms with their own experiences, which may include a desire to "do better" (see Solomon & George, 1996). On the other hand, children's attachment representations evolved within this specific parent–child relationship and are thus a measure of the dyadic relationship quality based on their real-life experiences together. Regarding INS, this is especially relevant as, in this case, increased INS may potentially mark well-functioning goal-corrected partnerships. Further research including different age groups may inform about the development of INS within the emerging attachment relationship in which both partners feel confident interacting while keeping the others' perspective in mind.

5.4 | Limitations and future perspectives

Some limitations deserve consideration. First, we only assessed a small number of interaction behaviors. Future studies should consider adding more task-relevant attachment-related behaviors as well as combining behavioral ratings with microcoding to assess their relation to INS and attachment representations. Second, we assessed mother–child and father–child dyads in a between-group and cross-sectional design. Repeated dyadic measurements of children interacting with both parents or triadic tasks are needed to elucidate the dynamics within the entire family. Furthermore, patterns of INS in parent-child dyads could be assessed by implementing a longitudinal study design that would allow for modeling the potentially bidirectional relations between INS and attachment development. Finally, we were unable to assess parentals and children's biological sex as well as attachment representations concerning INS in more detail. A larger sample size and pre-experimental screening enabling a more balanced number of mother-son, mother-daughter, father-son, and father-daughter pairs will allow for further differentiation in INS patterns within parent-child subgroups. Also, including a larger number of parents assigned to the insecure attachment groups (insecure-preoccupied vs. insecure-dismissing), future studies may consider modeling a quadratic association to test assumptions of an "optimum midrange model" to explain INS patterns.

6 | CONCLUSION

Sixty-five years after Harlow's pioneering work in rhesus monkeys on the "nature of love" (Harlow, 1958), we provide a novel approach to capture the brain basis of the inherently interpersonal process relating to the invisible tie that binds parents and their children. Specifically, we detected a link between differences in intraindividual attachment representations and dyadic processes visualized on the neural level, though not accessible by overt behavior in our study (see also Spangler & Zimmermann, 1999). Understanding these mechanisms may shed further light on determinants of interaction quality and inform research on the transmission of caregiving experiences across generations (see van IJzendoorn & Bakermans-Kranenburg, 2019).

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The Matlab & R analyses scripts are available at https://github.com/tnguyen1992/AAI_MDCARE. The data is available upon reasonable request and after signing a data sharing agreement with the corresponding author P.V.

ETHICS STATEMENT

Ethics approval was granted by the local ethics committee.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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