1 Introduction

Humans are inherently social beings who rely on affiliation for well-being and survival. Developing well-synchronized interpersonal relations is one way to facilitate social affiliation (Feldman, 2012). Dyadic interpersonal synchrony refers to the dynamic, reciprocal, temporal coordination of actions, thoughts, emotion, and physiology between two partners (Feldman, 2007). Synchronized interactions are built through mutual regulatory, bidirectional processes, where both members of the dyad play a role in shaping the interaction. Achieving dyadic synchrony allows both partners to move flexibly into and between coordinated states. Interpersonal synchrony is observed in infant-parent dyads from the early months of life and plays a key role in developmental outcomes (Feldman et al., 1996; Golds et al., 2022; Kellerman et al., 2020). In later years, interpersonal synchrony is fundamental to effective social exchange, facilitates cooperation, and is an essential component of social-cognitive functioning (Hove & Risen, 2009; Koehne et al., 2016; Valdesolo et al., 2010).

When studying interpersonal synchrony, it is critical for researchers to be clear about the type of synchrony that is under investigation. Dyadic interpersonal synchrony is a complex phenomenon that can be measured in many different ways, including through verbal and nonverbal communicative and emotional behaviors (e.g., talking, pointing, smiling, looking), movement patterns (e.g., direction and speed of motor behaviors), physiological measures (e.g., heart rate, respiration, cortisol, oxytocin), and patterns of neural activation (i.e., typically measured using fNIRS, EEG, MEG, fMRI). The focus of this Element is on methods that assess interpersonal synchrony through verbal and nonverbal behavior, movement patterns, and patterns of cortical activation. For more information on interpersonal synchrony as explored through rhythmic, coordinated physiologic responses, reviews are available (Bell, 2020; DePasquale, 2020; Feldman, 2007).

How one measures interpersonal synchrony is guided by the synchrony-related construct in which one is interested, and the behaviors that best exemplify that construct. Early in the first year, dyadic synchrony is observed in shared emotional states, joint attention, and temporally aligned movement patterns (Nguyen et al., 2020; Piazza et al., 2020). Synchrony is also observed in coordinated brain activity between social partners (Nguyen et al., 2020; Piazza et al., 2020). As social interactions become more varied and diverse during infancy, the manifestation of dyadic synchrony also evolves. These coordinated interactions between infants and their caregivers help infants form attachments, develop social skills, and provide opportunities to share knowledge (Feldman, 2007). Hence, it is critical to that we understand the intricacies of interpersonal synchrony from multiple perspectives. To do so requires a clear understanding of the methods that we use to test our research questions. With advances in technology, the techniques available to researchers to assess interpersonal synchrony in multiple modalities are rapidly changing.

Our overarching goal is to promote methods that allow us to better understand the origins and development of dyadic interpersonal synchrony as a bidirectional process that emerges within the many different contexts in which infants, parents, and caretakers interact. This Element begins by discussing traditional approaches to the assessment of infant-parent synchrony, which rely primarily on person-coded assessments of verbal and nonverbal behavior. Next, we introduce more contemporary approaches that incorporate technologically advanced methods for the automated coding of movement data. We will then discuss hyperscanning, focusing primarily on the use of functional near-infrared spectroscopy (fNIRS). Hyperscanning is a neuroimaging technique that measures neural activity in two or more individuals simultaneously during interactions. Hyperscanning is crucial for uncovering the neural underpinnings of interpersonal synchrony because it captures the dynamic and reciprocal nature of social interactions which cannot be fully understood by a traditional single-brain approach, in which the individual brain is studied in isolation.

We will discuss approaches that incorporate measures of behavior and brain simultaneously, using the relation between behavioral responses, movement patterns, and patterns of neural activation to understand the complex unfolding of dyadic interactions during social exchange. These interactional patterns can be measured in a number of dimensions, including when they occur, the strength with which they occur, the frequency with which they occur, and the phase in which they occur (e.g., who leads and who follows). Within this context, we will introduce a new method for analyzing signals obtained from behavioral and neural assessments that can provide more detailed information about the coordinated, dynamic temporal structure of infant-parent dyadic interactions. This method allows us to uncover the different types of interactions that occur between parents and their infants during different tasks. Together, these advancements will shed light on the processes that support early emerging social interactions and possible mechanisms for change in the quality and quantity of these interpersonal exchanges.

Our focus is primarily on infancy and toddlerhood (i.e., 3 months of age to 3 years of age). However, there are sections of this Element where the literature with this age group is sparse. Hence, we will turn to investigatory methods and data analytic techniques implemented in early childhood (i.e., 3 years of age to 6 years of age), and with older children and adults to explain why it is advantageous for developmental scientists to consider these alternatives.

Finally, most infant research investigating interpersonal synchrony has been conducted with infant-mother dyads, largely because mothers are more accessible research participants than fathers or other caregivers. In studies that have included fathers, some, but not all, have reported differences in the way that mothers and fathers temporally coordinate with their infants (Azhari, Bizzego, & Esposito, 2022; Feldman, 2007; Liu, Zhu et al., 2024; Lundy, 2023; Nguyen, Schleihauf, Kungl et al., 2021). The extent to which mothers and fathers differ in their dyadic interactions with their infants depends, at least in part, on how synchrony is measured and the context in which it is measured. We will be explicit when reporting findings from studies that included both mothers and fathers and in which gender differences were obtained.

2 Behavioral Measures of Interpersonal Synchrony

There is a long-standing interest in the developmental sciences in identifying the ways in which coordinated social interactions in infant-parent dyads are established and maintained. In this section, we first present person-coded measures of interpersonal synchrony, which have been used for many years in the assessment of infant-mother interactions. Person-coded assessments, which evaluate a broad range of verbal and nonverbal communicative and emotional behaviors, are frequently taken during spontaneous, unstructured play. This play context enables researchers to observe infant-parent interactions during a context that closely mirrors their everyday experiences. However, assessment can be done in more structured settings.

We then present more contemporary automated approaches to assessing behavioral interactions that include (a) wearable technology, which typically requires the use of specialized equipment in a lab setting, and (b) automatic coding of behavior, which utilizes computational methods to estimate synchronous behaviors in a video stream and is more flexible in the situations in which can be used.

2.1 Person-coded Measures

The most widely used behavioral assessments for evaluating interpersonal synchrony in infant-parent dyads rely on trained observers to code various aspects of verbal and nonverbal behavior during a dyadic interaction (see Table 1). These behaviors, often subtle and complex, are assigned numerical values that are averaged to produce composite or global scores reflecting the overall quality of the interaction. Person-coded measures typically include monadic global scores, which assess the behaviors of the infant or parent individually (e.g., infant engagement or parental sensitivity), as well as dyadic

Table 1 Person-coded assessments of interpersonal synchrony

Type and Description	Advantages	Limitations	Types of Research Questions
Global coding scales assess infant behaviors, parent behaviors, and dyadic coordination. Composite scores capture monadic constructs (e.g., maternal sensitivity, infant initiative) and dyadic constructs (e.g., dyadic reciprocity).	Well-established coding schemes with good psychometric properties are available. Verbal and nonverbal behaviors are considered. Composite scores can be used as predictor or outcome variables.	Time and resource intensive and susceptible to observer bias. Scores do not capture moment-to-moment changes in dyadic interactions.	How do monadic traits influence dyadic interactions? How do monadic and dyadic traits relate to developmental outcomes? How do interpersonal constructs measured through behavioral coding align with those assessed through other modalities? To what extent are individual and dyadic characteristics causes or consequences of other variables (e.g., emotion regulation, attachment)?
Micro-coding of infant and parent behaviors includes frame-by-frame analysis. The onset, offset, duration, and frequency of synchrony-related behaviors are coded.	Captures moment-to-moment changes in monadic and dyadic behaviors.	Time and resource intensive and susceptible to observer bias.	How do specific behaviors or classes of behaviors influence dyadic synchrony? How are synchrony-related behaviors related to developmental outcomes (e.g., language development or communicative behaviors)? What is the relation between the timing or onset of specific behaviors and that of neural synchrony?

Note: Person-coded measures are applied to a previously acquired video stream.

global scores, which evaluate the quality of the interaction between the two (e.g., dyadic reciprocity or mutual adaptation).

Person-coded measures of interpersonal synchrony are most often implemented by using a video-recorded session of the infant-parent interaction, which is then later coded offline. Projects that implement person-coded measures typically use video recordings from a 4- to 11-minute naturalistic free play task, although video recordings are sometimes obtained from tasks that are more structured (such as periods of interaction during feeding, bedtime, bath time), or during tasks of a direct experimental instruction (such as still-face procedures) (Leclère et al., 2014). We recommend using person-coded assessments during naturalistic free play interaction when the research question pertains to spontaneous dyadic infant-parent behaviors that occur during normal day-to-day interactions. Study designs that incorporate a naturalistic free play interaction may maintain more ecological validity and the behavioral findings may be more generalizable than would be for some structured research designs. If the research question is dependent on the study of a specific behavior (such as index-finger pointing) or situation (such as building a block tower), we recommend that the researcher implement person-coded assessments of behavior in a more structured study design to ensure that specific behavior or scenario of interest is present in the data.

Person-coded behavioral assessments that generate global scores are well-suited for statistical analyses that require a single score, or small set of scores, to represent the quality of infant-parent synchrony during the entire social interaction. Some behavioral methods include options for micro-coding, which provide detailed scores for specific behaviors observed over brief, targeted time intervals. Although definitions of synchrony may vary across disciplines and theoretical perspectives, within the developmental sciences synchrony is typically characterized by mutuality or reciprocity between partners, rhythmic and harmonious exchanges, and sustained engagement (for a review, see Leclère et al., 2014). Finally, though interpersonal synchrony is related to constructs such as parent sensitivity, interpersonal synchrony is a distinct construct that highlights temporal aspects of dynamic social interaction.

2.1.1 Implementation of Person-coded Measures

The investigator should consider their research question and study design (naturalistic vs. structured) when considering how best to record video data of the experiment and implement the person-coded measures. Best practices for offline coding of parent-infant synchrony include (but are not limited to) the coder's ability to clearly see the parent's and infant's facial expressions, hand gestures, and any objects of joint attention (such as toys), as well as the coder's ability to clearly understand the parent's words and the infant's vocalizations. To achieve the goal of full visibility, we recommend using multiple cameras positioned at different angles. For example, it may be beneficial to have cameras positioned to directly face the parent, the infant, and the dyad as a whole, as well as having an overhead camera that is positioned to obtain a view of the dyad's hands and objects of interest.

For research studies that require participants to attend to an object of joint attention, we advise that the participants be seated at a tabletop across from one another, allowing for ease of communication and joint involvement with the object. However, parents may be more comfortable playing on the floor than at a table. Choice of seating arrangement and toys/objects used during the session needs to be developmentally appropriate. For example, prior to about 7 months infants are unable to sit unsupported, hence will require trunk support to have their hands free during the task. Once infants gain the ability to sit independently, their reaching and object manipulation abilities improve (Bertenthal & Clifton, 1998; Rochat & Goubet, 1995; Soska et al., 2010), leading to greater mobility and object exploration skills. In comparison, older infants will not need sitting support but may benefit from an arrangement that keeps them in a location within camera view.

To increase ecological validity, researchers may choose to collect data in the home of the participants rather than in the laboratory setting. This can be done by bringing all necessary data collection tools (such as cameras, tripods, and any specific toys or objects needed) to the participant's home. The experimenter may also allow the participants to interact with any of their own toys or household items as they choose, rather than experimenter-chosen toys and objects, as the presence of familiar items may provide a more accurate picture of how the dyad interacts during their daily routines. Our team has had success collecting free play data from a home setting using online video conferencing software (Hammack et al., 2023). This method reduces the resources needed, maintains a naturalistic play setting, and increases the ecological validity of the experimental findings, as compared to researchers traveling to the participants' home. There are some disadvantages of online video data collection techniques, including attrition due to interruptions from other children or family members, technical or internet problems, bad lighting, noisy environments, or procedural problems (e.g., lack of a tabletop appropriately distanced from a camera). However, the advantages of online video data collection, including increased accessibility to a larger and more diverse group of participants in their natural environment, may outweigh the limitations of online video data collection.

2.1.2 Global Coding of Dyadic Qualities

By using a global coding approach, nuances in behavior can be evaluated by experienced coders, who evaluate a range of behaviors to obtain a global measure of dyadic constructs assessed across the entirety of the interaction. Global coding is well suited for the measurement of concepts such as reciprocity or mutuality and reflects the overall quality of the interaction within the scoring paradigm. This approach requires the coder to consider the wide context of the interaction when rating behaviors, which allows the investigator insights into the infant-parent relationship that would not be possible through means of self-report or the observation of the infant behavior alone.

Studies that use a dyadic approach to the study of infant-parent synchrony can provide information about the dyadic relationship that cannot be deduced from the coding of infant and parent behaviors individually. For example, mutually responsive orientation is an established dyadic construct that cannot be measured by assessing responsiveness and positive affect of each social partner individually (Aksan et al., 2006). Next, we will review popular measures that include dyadic constructs for the investigation of parent-child interactions.

Measures of Reciprocity. One well-validated global coding measure, the Coding Interactive Behavior scale (CIB; Feldman, 1998), uses a rating system to assess dyadic reciprocity and dyadic negative states. In the CIB, dyadic reciprocity indexes the degree of reciprocal turn-taking, adaptation to one another's emotional states and levels of interest and activity, and fluency of the interaction. A global score of dyadic reciprocity is calculated as an average score of three dyadic codes: dyadic reciprocity, dyadic adaptation-regulation, and dyadic fluency. The dyadic negative states measure is calculated as an average of two dyadic codes: dyadic constriction and dyadic tension. Other global coding measures, such as the Qualitative Ratings for Parent-Child Interaction scale (Owen et al., 1996), the Coding System for Mother-Child Interactions (CMSCI; Healey et al., 2010), and the NCAT Feeding and Teaching PCI scales (Keefe et al., 1996) assess similar dyadic constructs within the context of infant-parent interactions.

Measures of Synchrony. Other global coding techniques consider child-parent synchronous behaviors, whether it is the coder's perception of synchronous behaviors during interaction or the treatment of synchrony as a more global concept without measure of the temporal dynamics (see Leclère et al., 2014 for a review of coding techniques of infant-parent synchrony). The Bernieri's Scale (Bernieri et al., 1988), The Belsky Parent-Child Interaction Coding System (Isabella & Belsky, 1991), and the Synchrony Global Coding System (Skuban et al., 2006) measure the coder's perception of synchronous behaviors during interaction. The Coding Scheme and The Rocissano and Yatchmink Taxonomy require the coder to separate the interaction videos into several parts and rate overall synchrony across each part of the session. The Maternal-Infant Synchrony Scale assesses engagement during feeding interactions (Reyna et al., 2012). Similarly, the Rating Scale of Interactional Style (RSIS; Feldman et al., 1996), the Infant Caregiver Engagement (ICE) scale (Weinberg et al., 1999), and the Behavior State Coding Scale (Field et al., 1989) assess mutual synchrony as a global construct.

Measures of Mutuality. Some common global measures of dyadic infant-parent behaviors include measures of mutuality, which describe the "cooperative, smooth-flowing, and responsive nature of a parent and child engaging together" (see Funamoto & Rinaldi, 2015, for a review of child-parent mutuality coding schemes). Such measures of mutuality include The Parent-Child Interaction System (PARCHISY; Deater-Deckard et al., 1997), The Mutually Responsive Orientation Scale (MRO; Aksan et al., 2006), The Caregiver-Child Affect, Responsiveness, and Engagement Scale (C-CARES; Tamis-LeMonda et al., 2002), and the Synchrony and Control Coding Scheme (Mize & Pettit, 1997). These coding schemes cover several dyadic behaviors including communication, reciprocity, and coordination.

Studies that use a global approach to investigate infant-parent synchrony reveal a great deal about the factors that impact the early dynamic social relationship developing between infants and their parents (see Golds et al., 2022 for a review). For example, parental warmth and sensitivity is associated with higher levels of synchrony (Longhi, 2009; Thompson & Trevathan, 2009). Global approaches have also demonstrated that maternal mental health risk factors, such as depressive symptoms (Coburn et al., 2015; Field et al., 1989), emotion dysregulation (Lotzin et al., 2015), anxiety (Lemus et al., 2022; Moore et al., 2016), and maternal stress (Coburn et al., 2015; Lemus et al., 2022) are associated with lower levels of infant-parent synchrony. Additionally, studies using a global-coding approach have demonstrated the lasting impact that early-emerging infant-parent dyadic synchrony has on developmental outcomes. For example, greater interpersonal synchrony in the first year is associated with better expressive and receptive language skills (Kellerman et al., 2020), more symbolic play, and enhanced performance on intelligence tests years later (Feldman et al., 1996; Feldman & Greenbaum, 1997). In the social domain, studies using globally coded measures of infant-parent and toddler-parent synchrony demonstrate that synchrony is positively associated with better child self-regulation skills (see Davis et al., 2017 for a meta-analysis on the topic), and globally rated child-parent synchrony is predictive of child social skills and aggression in preschool-aged children (see Pasiak & Menna, 2015 for a review).

2.1.3 Micro-Coding of Interpersonal Synchrony

Micro-coding approaches are coding paradigms that allow trained coders to evaluate instances of infant and parent behaviors during specific timepoints during the interaction. By analyzing the time series of behavior from both social partners, researchers have the ability to investigate the temporal dynamics of infant-parent synchrony (i.e., how infant-parent synchrony changes throughout the course of an interaction). The paradigm may require the coder to identify both infant and parent instances independently, or instead to identify joint behaviors exhibited by both partners in the dyad (de Graag et al., 2012; Isabella et al., 1989). From either approach, a measure of interpersonal behavioral synchrony can be obtained by extracting simultaneous, sequential, or lagged behaviors (Feldman, 2007) that occur within the dyadic interaction during a specified time frame. Synchrony can be observed across many different behaviors. For example, researchers may choose to micro-code instances of joint attention, affective states, vocalizations, or nonverbal communications (Bizzego et al., 2022; Nguyen, Abney et al., 2021; Papoutselou et al., 2024; Piazza et al., 2020). In fact, synchrony among caregiver–child interactions often involves the coordination of intermodal behaviors. For example, mother-initiated acts may often involve verbal language paired with instances of child positive affect and gaze to mother. Distinct from constructs of imitation and mimicry, infant-parent synchrony is thought of as an "intricate dance" between social partners (Feldman, 2007) which can be operationalized through statistical analysis of the micro-coded time series (see Leclère et al., 2014 for a review of micro-coding approaches to study infant-parent synchrony).

Micro-coding of infant-parent synchronous behaviors is sometimes conducted on a frame-by-frame basis, meaning that the coder investigates behaviors on each frame in the video to identify specific onsets and offsets of behaviors as they occur. Sometimes researchers code behaviors in windows as narrow as 0.01 second frames (Atzil et al., 2014), or in windows as broad as three-second intervals (Doba et al., 2022). Although very narrow windows can increase the temporal resolution of the collected data, this may also increase the coding workload. The expected duration of the behavior of interest to the research question will determine the interval used. When micro-coding frame-by-frame, typically onsets are marked in the frame in which the specified behavior begins, and offsets are marked in the frame in which the specified behavior ends (Kellerman et al., 2020). Computerized coding systems, such as Noldus (Wageningen, the Netherlands) and Datavyu (Datavyu Team, 2014), can be used to assist in frame-by-frame micro-coding (e.g., Atzil et al., 2014; Feldman et al., 2011; Harel et al., 2010; Hoch et al., 2021).