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Intersubjectivity: Recent advances in theory, research, and practice

Edited by
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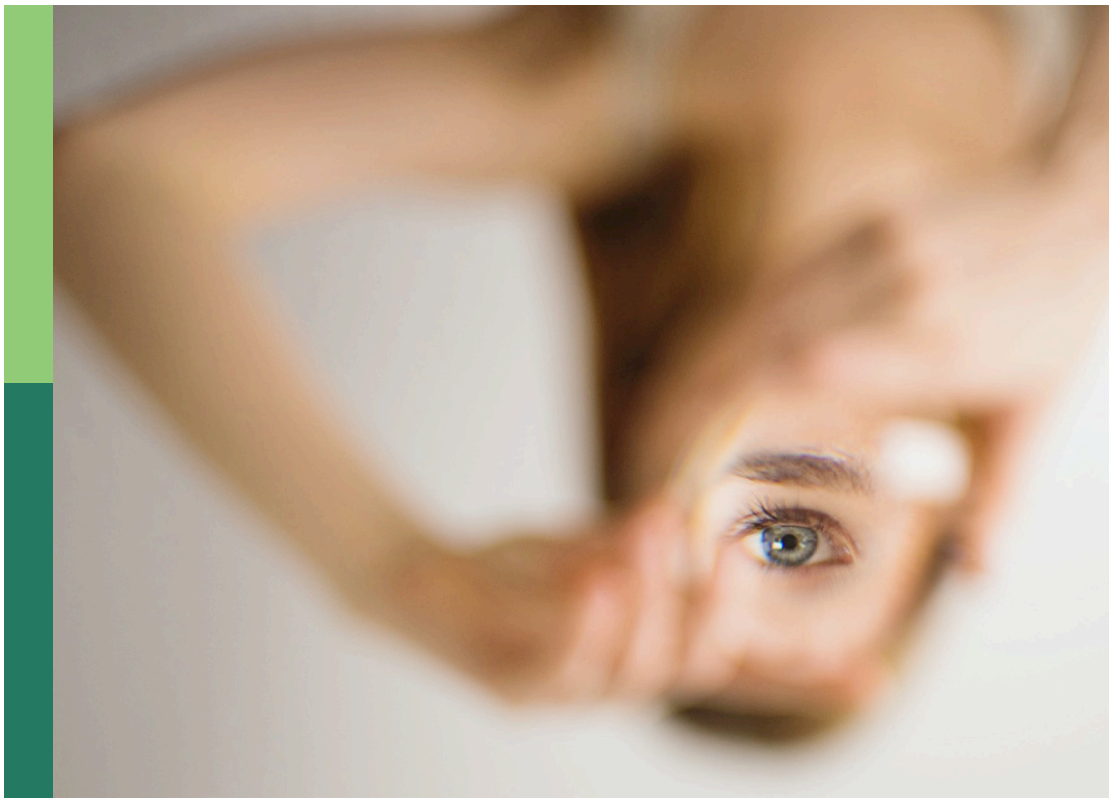

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Intersubjectivity: Recent advances in theory, research, and practice

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Editorial: Intersubjectivity: recent advances in theory, research, and practice

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Editorial on the Research Topic
Intersubjectivity: recent advances in theory, research, and practice

Intersubjectivity describes the awareness of self and other's intentions and feelings in the dynamic sharing of minds acting in companionship, exchanging self-conscious intentions and emotional evaluations. Since 1960, when studies of infants disproved the theory of the young mind as a sensory-motor computer that is "conditioned" to learn facts symbolized in language, psychology now highlights the natural science of infant awareness, intelligence, intentions, and emotions and their sharing in embodied, non-verbal participation with others. This has fundamental implications for support of children's health, growth and learning in Psychology, Education, Pediatrics, Psychiatry and Psychotherapy and for mental health of infants, parents and teachers. It has strong confirmation by recent functional brain science. In this Research Topic entitled "*Intersubjectivity: recent advances in theory, research, and practice*," we advance the science of intersubjectivity by bringing together new empirical studies, review, hypothesis and theory papers with advanced scholarship on the early emergence of human consciousness.

Introduction

Intersubjectivity theory has had a long and fruitful career over the last three quarters of a century. Stemming from the anthropological work of Mead (1928) and Bateson (1975), the notion of intersubjectivity was adopted by infant and developmental psychologist to explain the pre-verbal dynamic sharing of interests, emotion, and intentions in face-to-face dyadic engagements between infant and parent (Trevarthen, 1998), and in developmental studies of and how children share in the rituals and spontaneous projects of home life that over the early years carries a child into the mastery of language (Stern, 2000; Nagy, 2008; Goodrich, 2010; Kokkinaki and Vitalaki, 2013; Trevarthen and Delafield-Butt, 2013, 2017; Delafield-Butt and Trevarthen, 2015).

Intersubjectivity theory is inherently an embodied science of mind (Trevarthen, 2012; Paolo and Jaegher, 2015), attending with scientific precision to the pre-verbal production of body movement to express and invent actions of thought in co-created meaning with

another as the foundation of psychological developmental and later life productions of art, technology and tool use. Discovery of a culture in childhood involves learning a special form an embodied and enactive knowledge distinct from the learning theories of Pavlov and challenged by Bernstein (1967) who identified movement as the substrate of imaginative knowledge, and sharing ways of life. These rituals and their idiosyncratic experiences shared with caring and attentive others make up the stories that structure cultural learning (Bruner, 1977, 1990, 2004).

The science of intersubjectivity, with its understanding of feelings, embodiment, and companionship, is needed more today than it ever has been. With increasing attention to artificial intelligence and artificial worlds generated through the medium of technology, it is important to remind ourselves of the psychological and biological nature of how minds are shared, and come together make meaning and sense of the world in common purpose. They do this through sharing feelings, the affects and intentions that coordinate the body and compose the mind to work in step and in fluid efficiency with another mind. The peculiar psychobiology of intersubjectivity demonstrated long ago that this coming together of minds does so to generate something coherent and additional, more than the sum of its parts. This *inter-* (between or among, reciprocal) *subjectivity* (the experience of mind) is the foundation of human sharing, shared understanding, learning, and culture (Trevarthen and Hubley, 1978; Tronick, 2001).

That its study is credited in the early anthropology of Mead (1928) and Bateson (1971, 1975) is not to be missed. The science of intersubjectivity teaches us how minds are shared to generate micro (family) cultures and macro (societal) cultures, and all the nuances in between, especially in relation to health and learning, or pathology (Trevarthen et al., 2006). This science of intersubjectivity is only just beginning to reap rewards for societal and health benefit, and in the improvement of life for those with non-traditional and non-verbal voices and means of communication, such as infants or those with disruption to the typicality of fluid verbal speech.

In this special Research Topic, we have brought together a sample of important papers and perspectives that advance step-wise the science of intersubjectivity, from its underpinning neurobiology, its earliest development in premature birth, early childhood education and care, its cultural, psychological health, and human rights concerns. These papers contribute to improved understanding of our human nature, rich with affective resonances between us, and underpinning by a basic psychobiology that shares minds effortless between us. Knowing this with greater precision, and reflective conscious awareness enables better care and attention to those we seek to support.

Below we detail to give quick overview to the papers in this Research Topic.

An interpersonal neurobiological model of the ontogeny of intersubjectivity

Schore ("*The interpersonal neurobiological of intersubjectivity*") proposes an interpersonal neurobiological model of the ontogeny of intersubjectivity. He describes intersubjectivity as right-lateralized interbrain synchronization between the psychobiologically attuned mother and the developing infant while co-constructing engagement. These shared intersubjective interactions facilitate the maturation of the "social brain," the temporoparietal junction of the right brain in the infant, leading to highly complex behavioral and interbrain synchronization. Based on recent brain laterality research, the clinical applications of this interpersonal neurobiological model of intersubjectivity are discussed.

Precursors of effective and positive interactions as soon as birth in interactions of mothers with very preterm and full-term newborns

A pioneering study by Buil et al. explored how intersubjective communication can be facilitated by skin-to-skin positioning very preterm, 27-31 weeks-old gestational old newborns on their mothers, soon after birth ("*Skin-to-skin SDF positioning: the key to intersubjective intimacy between mothers and very preterm newborn—A pilot matched-pair case-control study*"). In a prospective, matched-pair study, Buil et al. placed the babies either in Supported Diagonal Flexion (SDF) positioning, where the pair can comfortably see each other, or in a Vertical position, where the mother sees mostly the top of her baby's head. The team then frame-by-frame coded the babies' states of consciousness, the babies' and mothers' vocalizations, and acoustic turn-taking, and found that in comparison to the vertical group, mothers in the SDF group offered a denser vocal envelope, with longer vocalizations, and the temporal proximity of the mothers' and babies' communication was greater. Overall, the authors propose that SDF promotes behavioral and brain-to-brain synchrony in premature baby-mother pairs.

Guellai and Streri ("*Mouth movements as possible cues of social interest at birth: new evidences for early communicative behaviors*") showed that newborns as early as in the first days of life, produced more mouth movements when they saw a video of someone talking to them rather than a video of someone looking at them silently moving. Frequencies of mouth movements in the newborns were greater and the latency of the first mouth movement was shorter in front of a static face, compared to a dynamic face. The authors proposed that newborns already have a "sense of interaction" from birth, and they utilize motor feedback the interactive partner to time and shape their own responses.

Dialogic book sharing as a privileged intersubjective space

Murray et al. focus on "Dialogic Book-Sharing" (DBS), an intersubjective form of using books with children. Through the evidenced-based justification on why involved processes (gaze following, pointing, naming and animating and special linguistic characteristics of book-sharing) are beneficial, the authors integrate evidence ranging from non-human primate communication to experimental and naturalistic studies of infant attention, cognitive processes and language. The authors argue that DBS is an

intersubjective process of dynamic engagement and a natural propensity to share meaning. They highlight the importance of promoting DBS in effective training programmes, especially in disadvantaged populations as a powerful way to reduce economic inequality.

Primary and secondary intersubjectivity: the continuity vs. discontinuity debate

Based on the fact that secondary intersubjectivity and the emergence of words are built on a foundation of primary intersubjectivity and with the aim to highlight the evolutionary origins of intersubjectivity, in their review paper, Terrace et al. ("*Intersubjectivity and the emergence of words*") postulate that there is continuity between primary and secondary intersubjectivity and that both are necessary for the emergence of words. Even from birth, babies produce vocalizations called protophones that form part of the first vocal protoconversations, and are embedded in a multimodal, gestural turn-taking, that form a narrative, much before language develops. Taken the incremental changes measured in the development of most intersubjective abilities, Terrace et al. argue for a continuity, rather than a stage view of intersubjective development.

In Moll et al.'s hypothesis and theory paper, the authors contrasted two theses. The primary intersubjectivity thesis (PIT) highlights the humans' innate relational capacity from which social knowledge and understanding emerges. The shared intentionality thesis (SIT) postulates that human-unique forms of interaction develop through a cognitive revolution at 9-12 months of age when infants participate with others in acts of joint attention, imitative learning and cooperative action. The authors unified the strengths of the two theses and attempted to build a bridge between the PIT and the SIT by sketching how one expands into the other in a continuous process.

Cross cultural aspects in resonance of timing, anticipation and empathy

In the cross-cultural study of aspects of intersubjectivity, Negayama et al. compared interactional synchrony in feeding between Japanese and Scottish mother-infant dyads. Different elements of timing, anticipation and empathetic mirroring underpinning mother-infant feeding process indicate two different cultural types of intersubjectivity in Japan and Scotland, which, according to the authors, become culturally and inter-generationally transmitted.

Intersubjectivity as an antidote to stress

By using intersubjectivity as a hallmark of quality dyadic processes and within the framework of Free-Energy Principle, Ho et al. introduced a dyadic active inference model integrating basic dyadic concepts, to show the inverse relationship between stress and intersubjectivity. Using this model and through a theory-driven quantitative review, the authors supported their hypothesis that parenting intervention can effectively reduce parenting stress. Inspired by Buddhist Madhyamaka Philosophy, championed by Arya Nagarjuna and in order to elucidate the relation between intersubjectivity and wellbeing, the authors describe a relational worldview in terms of an abstract expression of Dependent Origination and applied this expression to the domains of physics, awareness, intersubjectivity and active inference.

Interpreting loneliness within the theory of intersubjectivity

In her opinion paper, Galanaki (*Loneliness and intersubjectivity: A view from Trevarthen's theory*) argues that loneliness - the distress and social pain stemming from being alone - may be conceptualized within Trevarthen's developmental theory of intersubjectivity which focuses on innate-Other awareness.

According to the author, loneliness originates from humans' social brain, allocentric perception and innate dialogicity and thus may constitute a social or relational emotion. Social emotions are the causes of co-consciousness, of self-other awareness. Loneliness may be regarded as a moral emotion, as a motive for sympathy – a bridge between persons expressing their mutual assistance- belonging to our moral core. Moral emotions may facilitate sharing of meanings and purposes between sympathetic persons. A person's loneliness can be regarded as an innate intersubjective motive, a motive for seeking human company which floats in between persons and moves others. Solitude (an experience related to loneliness but distinct from it), evident even in very young infants, is a state of self-synchrony, a solitary state of reflection and contemplation. Early in life, private thinking and social communication co-exist in complementary ways.

Based on the implications of interpreting loneliness from the intersubjectivity view (existential disruptions, distortions of co-regulation and sharing, failure to co-construct meaning, to find cultural membership and to co-create a narrative about cosmos), the author concludes that "loneliness arises in a community of minds and is moderated by cultural membership and cultural sharing."

Intersubjectivity and rhythmic relating in atypical development

Heimann and Holmer ("*Neonatal imitation, intersubjectivity and children with atypical development: do observations on autism and down syndrome change our understanding?*") showed that neonatal imitation was observed both in a case of a newborn who later developed ASD and in five, 1-month-old babies with DS. The authors suggest an updated model outlining two possible trajectories for children later receiving an ASD diagnosis. The authors conclude that imitation might not represent a useful predictor of a developmental deficit. Both children with ASD and DS are born with the ability for primary intersubjectivity, and the

imitative ability documented in this research can enable them to enter into the first dialogues.

Based on the parameters of Communicative Musicality (pulse, quality and narrative), and on a thorough review of disruptions to social timing, sensorimotor timing and integration in autism, Daniel et al. ("*Rhythmic relating: bidirectional support for social timing in autism therapies*") proposed Rhythmic Relating. Rhythmic Relating is a system and a skill set which aims to augment bidirectional communication and facilitate the predictive flow and just-a-head in time planning needed for social timing in child-centered therapeutic approach to interaction with individuals with autism.

Harrison and Tronick ("*Intersubjectivity: conceptual considerations in meaning-making with a clinical illustration*") integrate three interrelated elements of meaning-making, that is meaning-making in interactions, making meaning with the body as well as the mind, and meaning-making within an open dynamic system, into a conceptual construct. The authors discuss the usefulness of this construct in psychoanalysis and provide clinical insights through the application of it as a dynamic evolving, multifaceted and non-linear "messy" process in the treatment of a 3-year-old child on the autistic spectrum.

Intersubjectivity and pre-verbal children's rights

Våpenstad and Bakkenget ("*Pre-verbal children's participation in a new key. how intersubjectivity can contribute to understanding and implementation of child rights in early childhood*") challenge the exclusion of preverbal infants' right to participate in relation to the United Nations Convention on the Rights of the Child (UNCRC) request for a definite way of involving infants. Based on the well-established ability of pre-linguistic children to communicate their interests, feelings and intentions through sympathetic rhythms, the authors propose that the voice of the infant can surface in adults verbal and musical narratives.

As the final article of the "*Intersubjectivity: recent Advances in theory, research, and practice*" *Research Topic* highlighted we all promote the recommendation of the United Nations on the Rights of the Child (2005) that research on methods for infant participation should be given the highest priority. Even the youngest children have the ability to participate, and must have the rights to be heard, accepted, respected. Colwyn Trevarthen, a leading pioneer in the field of child development and intersubjectivity warned that a failure to provide care and companionship to babies and toddlers inevitably results in major global issues in mental and physical wellbeing, that has further, immeasurable impact on economy, to form the foundation of our cultural values, how we respect and work with the infant to support his or her learning, growth and psychological development (Trevarthen et al., 2018a,b).

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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The Interpersonal Neurobiology of Intersubjectivity

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In 1975, Colwyn Trevarthen first presented his groundbreaking explorations into the early origins of human intersubjectivity. His influential model dictates that, during intimate and playful spontaneous face-to-face protoconversations, the emotions of both the 2–3-month-old infant and mother are nonverbally communicated, perceived, mutually regulated, and intersubjectively shared. This primordial basic interpersonal interaction is expressed in synchronized rhythmic-turn-taking transactions that promote the intercoordination and awareness of positive brain states in both. In this work, I offer an interpersonal neurobiological model of Trevarthen's intersubjective protoconversations as rapid, reciprocal, bidirectional visual-facial, auditory-prosodic, and tactile-gestural right brain-to-right brain implicit nonverbal communications between the psychobiologically attuned mother and the developing infant. These co-constructed positive emotional interactions facilitate the experience-dependent maturation of the infant's right brain, which is in an early critical period of growth. I then address the central role of interpersonal synchrony in intersubjectivity, expressed in a mutual alignment or coupling between the minds and bodies of the mother and infant in face-to-face protoconversations, as well as how these right brain-to-right brain emotional transmissions generate bioenergetic positively charged interbrain synchrony within the dyad. Following this, I offer recent brain laterality research on the essential functions of the right temporoparietal junction, a central node of the social brain, in face-to-face nonverbal communications. In the next section, I describe the ongoing development of the protoconversation over the 1st year and beyond, and the co-creation of a fundamental energy-dependent, growth-promoting social emotional matrix that facilitates the emergence of the highly adaptive human functions of mutual play and mutual love. In the final section, I discuss the clinical applications of this interpersonal neurobiological model of intersubjectivity, which has a long history in the psychotherapy literature. Toward that end, I offer very recent paradigm-shifting hyperscanning research that simultaneously measures both the patient and therapist during a psychotherapeutic interaction. Using the Trevarthen's two-person intersubjective model, this research demonstrates changes in both brains of the therapeutic dyad and the critical role of nonverbal communications in an emotionally-focused psychotherapy session. These studies specifically document interbrain synchronization

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between the right temporoparietal junction of the patient and the right temporoparietal junction of the clinician, a right brain-to-right brain nonverbal communication system in the co-constructed therapeutic alliance. Lastly, I discuss the relationship between the affect communicating functions of the intersubjective motivational system and the affect regulating functions of the attachment motivational system.

Keywords: intersubjectivity, right brain, right temporoparietal junction, nonverbal communication, interpersonal synchrony, interbrain synchronization, brain laterality development, psychotherapy

INTRODUCTION

In 1975, Colwyn Trevarthen first presented his groundbreaking explorations of the origins of human intersubjectivity. In the subsequent five decades, his ongoing studies continue to confirm, elaborate, and expand upon these pioneering efforts and to make an enduring contribution to our understanding of early human development. Anchored in what has now become a large body of studies in developmental neuroscience, the central organizing principle of the theory dictates that, from the very beginnings of life, the infant is receptive to and aware of the subjective states of others, particularly the primary attachment object, the mother. This adaptive ability of the infant to bidirectionally communicate its affective states is especially activated in the moments of intimate dyadic free play. His seminal work, confirmed by other major developmental researchers, demonstrated that this capacity for primary intersubjectivity specifically emerges at 2–3 months. At 8 weeks babies are ready to engage in behavioral turn-taking when they expect social contingency, which consists of predictable back-and-forth interactivity. In such face-to-face, eye-to-eye intersubjective emotional communications, the infant and mother, intently looking and listening to each other, synchronize and mutually regulate their emotional states. Indeed, during these protoconversations, the emotions of both members of the dyad are expressed and actively perceived in spontaneous, reciprocal, and rhythmic-turn-taking interactions (Trevarthen, 1993).

Within this relational context of primary intersubjectivity, the baby, attracted by the mother's voice, face expressions, and hand gestures, replies playfully with affection, imitating and provoking imitations. In the same moment, the mother attentively watches and listens, anticipating the baby's expressions intuitively, and sympathetically replies to the infant's communications with emotional facial expression, prosodic motherese, and emotional touch. Thus, in this protoconversation of synchronized and coordinated visual facial, auditory, and tactile emotional signals, the mother-infant dyad co-creates an intersubjective reciprocal system of nonverbal communication (see **Figure 1**). Trevarthen concluded that "The emotions constitute a time-space field of intrinsic brain states of mental and behavioral vitality that are signaled for communication to other subjects and that are open to immediate influence from the signals of these others" (Trevarthen, 1993, p. 155).

Trevarthen (1990, p. 357) observed that this synchronized two-way traffic of reciprocal nonverbal signals elicits instant emotional effects, namely the positive effects of joyful pleasure and excitement build within the emotion transacting protoconversation. But his synchronization model also focused on internal structure-function events, as he stated "the intrinsic regulators of human brain growth in a child are specifically adapted to be coupled, by emotional communication, to the regulators of adult brains." These regulated intersubjective interactions permit the intercoordination of positive affective brain states within the emotionally communicating dyad. His work underscored the fundamental principle that the baby's brain is not only affected by these relational emotional transactions, but also its growth literally requires brain-brain interaction in the context of a burgeoning positive affective *relationship* between the mother and her infant. This fundamental interactive mechanism requires older brains to engage with mental states of awareness, emotion, and interest in younger brains and involves coordination between the subjective feelings of an adult and the intersubjective motivations of the infant to forge an emotional bond with the mother.

Trevarthen (1990, p. 335) emphasized the critical role of interpersonal resonance in these intersubjective communications:

> Corresponding generative parameters in…two subjects enable them to resonate with or reflect on one another as minds in expressive bodies. This action pattern can become 'entrained,' and their experiences can be brought into register and imitated. These are the features that make possible the kind of affectionate empathic communication that occurs, for instance, between young infants and their mothers (1993, p. 126).

Furthermore, he observed "Adaptation of a given brain to a particular social world depends…on a motivated search by the young for certain target experiences (as in) expressing mental or motivational states to others, and getting into contact with their mental states." In this dyadic state of interpersonal resonance, the infant is "able to exhibit to others at least the rudiments of individual consciousness and intentionality" (Trevarthen and Aitken, 2001, p. 5). Thus, this two-person interpersonal context of primary intersubjectivity also serves as a developmental origin of not only subjectivity but also "self-consciousness."

In this work, I shall offer an interpersonal neurobiological model of Trevarthen's intersubjective protoconversations between the mother and her 2–3-month-old preverbal infant. Following the article outline in the abstract, in the upcoming sections, I will offer an operational definition of intersubjectivity as rapid, reciprocal, bidirectional right brain-to-right brain visual-facial, auditory-prosodic, and tactile-gestural positively valenced

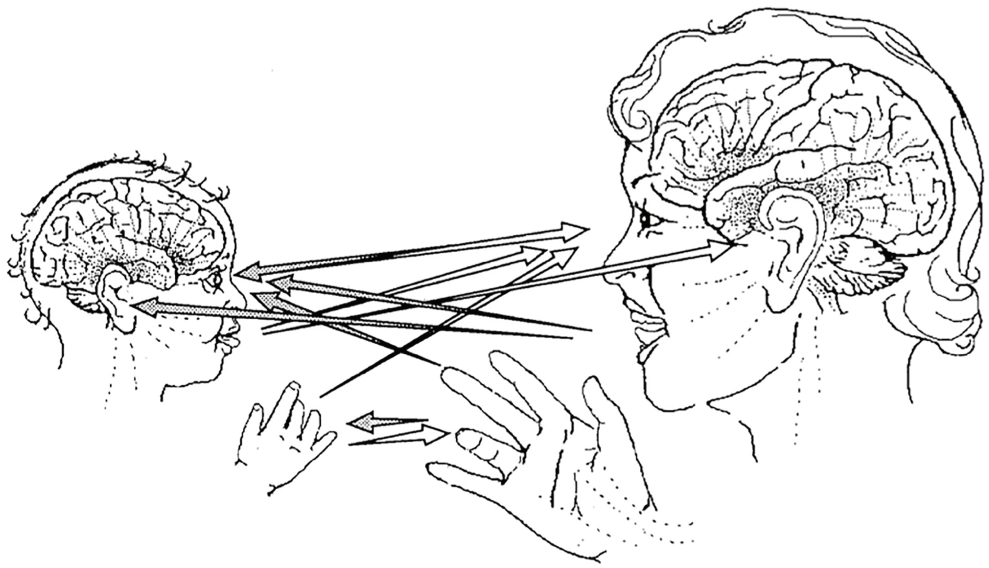

FIGURE 1 | Channels of face-to-face communication in primary intersubjectivity. Protoconversation is mediated by synchronized intersubjective eye-to-eye orientations, vocalizations, hand gestures, and movements of the arms and head, all acting in coordination to express interpersonal awareness and emotions. From Trevarthen (1993).

nonverbal communications between the mother and her developing infant. Expanding this model, I then discuss the fundamental role of interpersonal synchrony in intersubjective protoconversations, as well as how these right-lateralized emotional transmissions generate bioenergetic positively charged interbrain synchrony within the dyad. I then cite recent brain laterality research on the essential functions of the right temporoparietal junction, a central node of the social brain, in face-to-face nonverbal communications. In the following section, I discuss the continued development of right brain intersubjectivity in the 2nd year and beyond, and the relational origins of the highly adaptive functions of mutual play and mutual love. In the final section, I offer thoughts on the clinical applications of Trevarthen's intersubjectivity and protoconversations in psychotherapy, offering very recent hyperscanning research that demonstrates a right brain-to-right brain nonverbal emotional communication system embedded in the co-constructed therapeutic relationship. I end by offering thoughts on the relationship between the affect communicating functions of the intersubjective motivational system and the affect regulating functions of the attachment motivational system.

REGULATION THEORY MODELS INTERSUBJECTIVITY AS RIGHT-LATERALIZED NONVERBAL EMOTIONAL COMMUNICATIONS

In my own studies on the early development of intersubjective nonverbal emotional communication, I have utilized the interdisciplinary perspectives of interpersonal neurobiology and regulation theory, a theory of the development, psychopathogenesis, and treatment of the subjective self (Schore, 1994/2016, 2003a,b, 2012a, 2019a,b). The central focus of this psychoneurobiological model of human development is to more deeply understand the underlying mechanisms by which the structure and function of the mind and brain are shaped by experiences, especially those embedded in emotional relationships, as well as the relational mechanisms by which communicating brains synchronize and align their neural activities with other brains. With respect to this nonverbal communication between brains, I have drawn upon the overlap of Trevarthen's work on intersubjectivity and the Bowlby's on attachment theory. Although the former focused on emotion transacting events early in the 1st year and the latter on emotional events late in the 1st and 2nd year, both offered a similar model of nonverbal visual-facial, auditory-prosodic, and tactile-gestural communications between mother and infant.

In a mirror image of Trevathen's two-way traffic of emotional facial expressions, gestures, and vocal expressions, Bowlby (1969, p. 120) proposed that mother-infant attachment communications are "accompanied by the strongest of feelings and emotions, and occur within a context of facial expression, posture, and tone of voice." Interestingly, as opposed to Bowlby, Trevarthen's research was directly informed by extensive studies of developmental brain laterality (see his 1996 "Lateral Asymmetries in Infancy: Implications for the Development of the Hemispheres"). Indeed, in that publication, he noted that the prosody of the voice of the mother is responded to by the infant's right hemisphere. He also concluded that "The right hemisphere is more advanced than the left in surface features from about the 25th (gestational) week and this advance persists until the left hemisphere shows a post-natal growth spurt starting in the second year" (Trevarthen, 1996, p. 582).

Following these valuable leads, in my first book *Affect Regulation and the Origin of the Self* (1994), I drew upon a large body

of research on brain laterality and hemispheric asymmetries of structure and function to describe the intersubjective protoconversation as a right-lateralized, reciprocal, and nonverbal emotion communication system. Toward that end, I cited a large number of extant researchers who offered evidence on the early development of right hemisphere (see Schore, 1994/2016 for references) and concluded that the essential adaptive capacity of intersubjectivity is specifically impacted by the infant's early social experiences. Since these social interactions are occurring in a critical period of right brain growth, the child is using the output of the mother's right cortex as a template for the imprinting, the hard wiring of circuits in his own developing right cortex that will come to mediate his expanding social-emotional capacities to appraise variations in both external and internal information. I further proposed that, over the course of human infancy, these right brain-to-right brain nonverbal affective communications represent a relational context in which the primary caregiver psychobiologically attunes to and regulates the infant's internal states of autonomic nervous system and central nervous system arousal. Although Trevarthen stressed the role of intersubjectivity in positively charged play states, my work also addressed the nonverbal intersubjective communications of negatively valenced emotional states between the infant's mind/body and the mother's mind/body.

More recently, I have suggested that intersubjective mother-infant nonverbal communications directly influence the "early life programming of hemispheric lateralization" (Stevenson et al., 2008, p. 852) and are a major contributor to dominance of the right brain in human infancy (Schore, 1994/2016; Chiron et al., 1997). Neuroscientists are now asserting that one measure of healthy development in infants is lateralized behavior (Hall et al., 2008). A large body of laterality research in developmental neuroscience demonstrates the adaptive role of the infant's early maturing right brain in processing visual-facial, auditory-prosodic, and tactile-gestural nonverbal communications (Schore, 2003a, 2012a, 2019a). Indeed, over all stages of human development, "The neural substrates of the perception of voices, faces, gestures, smells, and pheromones, as evidenced by modern neuroimaging techniques, are characterized by a general right-hemispheric functional asymmetry" (Brancucci et al., 2009, p. 895).

With respect to *visual-facial nonverbal communications*, it is now established that mutual gaze is essential for early social development (Trevarthen and Aitken, 2001). The development of the capacity to efficiently process information from faces requires visual input to the right (and not left) hemisphere during infancy (LeGrand et al., 2003). At 2–3 months of age infants show right hemispheric activation when exposed to a woman's face (Tzourio-Mazoyer et al., 2002). By 6 months, infants express a right-lateralized, left gaze bias when viewing faces (Guo et al., 2009) and significantly greater right frontotemporal activation when viewing their own mother's (as opposed to a stranger's) face (Carlsson et al., 2008). On the other side of the mother-infant dyad, a large body of adult research indicates that the right occipital-temporal cortex generates a holistic face representation at 170 ms after stimulus onset, beneath conscious awareness (e.g., Jacques and Rossion, 2009).

Ongoing developmental neurobiological studies of *auditory-prosodic nonverbal communications* reveal that maternal infant-directed speech ("motherese") activates the right temporal area of 4–6-month-old infants, and that this activation is even greater in 7–9-month-old infants (Naoi et al., 2011). Seven-month-old infants respond to emotional voices in a voice-sensitive region of the right superior temporal sulcus, and happy prosody specifically activates the right inferior frontal cortex (Grossmann et al., 2010). These authors conclude that "The pattern of findings suggests that temporal regions specialize in processing voices very early in development and that, already in infancy, emotions differentially modulate voice processing in the right hemisphere" (2010, p. 852). As to the mother's emotional prosodic participation very recent adult research demonstrates a "right-lateralized unconscious, but not conscious processing of affective environmental sounds" (Schepman et al., 2016, p. 606).

With respect to *tactile-gestural nonverbal communications*, Sieratzki and Woll (1996) describe the effects of touch on the developing right hemisphere and assert that the emotional impact of touch is more direct and immediate if an infant is held to the left side of the body (see the studies of "left sided cradling" and activation of the right hemisphere in mother and infant in Schore, 2012a, 2019a). Nagy (2006, p. 227) documents a "lateralized system for neonatal imitation" and concludes that "The early advantage of the right hemisphere in the first few months of life may affect the lateralized appearance of the first imitative gestures." Developmental research demonstrates the essential role of maternal "affective touch" on human infant development in the 1st year of life (Ferber et al., 2008). This allows the infant and mother to create a system of "touch synchrony" in order to alter vagal tone and cortisol reactivity (Feldman et al., 2010). The dyad thus uses "interpersonal touch" as a communication system, especially for the communication and regulation of emotional information.

In order to process these intersubjective nonverbal communications, the infant seeks proximity to the mother, not just physical proximity but intersubjective emotional proximity, face-to-face, mind-to-mind, and body-to-body communications. During these nonverbal communications, the sensitive primary caregiver's right brain implicitly (unconsciously) attends to, perceives, recognizes, appraises, and regulates nonverbal expressions of the infant's more-and-more intense states of positive and negative affective arousal. The temporal dynamics of these intersubjective, rapid, spontaneous, and bodily-based right brain nonverbal communications are described by Lyons-Ruth, who observes that implicit, nonconscious processing of nonverbal affective cues in infancy "is repetitive, automatic, provides quick categorization and decision-making, and operates outside the realm of focal attention and verbalized experience" (1999, p. 576). Lyons-Ruth (1999) characterizes a "two-person unconscious" in the intersubjective dialog. From an interpersonal neurobiological perspective, intersubjectivity represents a co-created system of unconscious communications of positive and negative affect between two subjective minds, throughout the life span. My ongoing studies in the field of neuropsychoanalysis, the neuroscience of unconscious processes,

continues to offer interdisciplinary evidence showing that the right brain, the psychobiological substrate of the human unconscious mind, acts as a relational unconscious that communicates with another relational unconscious (e.g., Schore, 2003b, 2011, 2012a, 2019b).

RIGHT-LATERALIZED INTERPERSONAL SYNCHRONY IN FACE-TO-FACE PROTOCONVERSATIONS

In this section, I would like to return to Trevarthen's groundbreaking descriptions of infant-mother synchrony in face-to-face protoconversations. Aitken and Trevarthen (1997) asserted that

> In interaction between a normal infant and a happy and receptive caregiving companion the dual intrinsic motive formation systems of the two subjects are mutually supportive in rhythmic, sympathetic engagements which demonstrate *synchrony and turn-taking* in utterances and clear flexible emotionally toned phrasing with affect attunement (p. 667, italics added).

These authors documented the critical role of facial movements, voice, and gesture used by infants in their synchronized engagement with mothers. The timing and organization of playful events between infants and mothers allow the child to adaptively *synchronize* their *subjective* states of mind so that purposes, interests, and feelings are shared, *intersubjectively*. Indeed, interpersonal synchrony is a central construct that lies at the core of Trevarthen's right brain-to-right brain intersubjective protoconversation.

In this same time period, parallel studies using simultaneous two camera videotape recordings of the mother-infant interaction confirmed the centrality of interpersonal synchrony: Ed Tronick and Berry Brazelton (Tronick et al., 1977), Beatrice Beebe and Dan Stern (Jaffe et al., 2001), and Dorothy Feldman (Feldman et al., 1999). These latter authors were exploring moments of "affect synchrony" that occur in dyadic positive affectively charged social play, clearly reflecting Trevarthen's primary intersubjectivity:

> Face-to-face interactions, emerging at approximately 2 months of age, are highly arousing, affect-laden, short interpersonal events that expose infants to high levels of cognitive and social information. To regulate the intensity of their affective behavior within lags of split seconds (Feldman et al., 1999, p. 223).

Feldman et al. observed that, in this infant-leads-mother-follows sequence effect, synchrony affords infants "their first opportunity to practice interpersonal coordination of biological rhythms, to experience the mutual regulation of positive arousal, and to build the lead-lag structure of adult communication" (p. 223). Furthermore, they asserted that "Synchrony in dynamic systems…reflects the degree to which interactants *integrate* into the flow of behavior the ongoing responses of their partner and the changing inputs of the environment" (p. 224, italics added).

Over 25 years ago, in my first book *Affect Regulation and the Origin of the Self*, I cited the classic research of Lester et al. (1985) who asserted that "synchrony develops as a consequence of each partner's learning the rhythmic structure of the other and modifying his or her own behavior to fit that structure" (p. 24). The word "synchrony" derives from the Greek words *syn*, which means the same or common, and *chronos*, which means time, and so "synchrony" literally means "occurring at the same time." Across literatures the construct of synchrony is tightly associated with affective reciprocal interchange, emotion transmission, physiological linkage, and coregulation, all aspects of an intersubjective protoconversation. In a reciprocal, turn-taking communication system both individuals align, synchronize, and match their psychobiological states and then simultaneously adjust their social attention, stimulation, and accelerating arousal to each other. This synchronization occurs at different levels, from neural activity, to physiological states, such as heartbeat rhythm, to pupil size, to facial expressions and body postures (see Schore, 2019a, for references).

A large body of developmental research now documents mother-infant physiological synchrony at 3 months (Moore and Calkins, 2004), 6 months (Moore et al., 2009), and 12 months (Ham and Tronick, 2006) of age, a period when the mother-infant nonverbal affective protoconversations become more complex. Feldman's laboratory shows that mother and infant coordinate autonomic heart rhythms in moments of interaction synchrony (Feldman et al., 2011). These studies describe the longitudinal development of the capacity for synchronized intersubjective communications between the mother's mind/body and the infant's developing mind/body, as well as the enduing impact of early emotional communications on the adaptive capacity for intersubjectivity over later stages of human development. Indeed, mother-child behavioral synchrony is individually stable from infancy through adolescence (Feldman, 2010). Interestingly, in a recent study of what Feldman now terms "social synchrony" in mother-child dyads, she is calling for a "move from focus on one-brain functioning to understanding how two brains dynamically coordinate during real-life social interactions" (Levy et al., 2017, p. 1036) and, in other words, research on *interbrain synchronization*. Note that interpersonal synchrony refers to a synchronization of subjective states, involuntary behaviors, and physiological rhythms between the minds and bodies of two individuals, while interbrain synchrony refers to an alignment of brains between two individuals. Over four decades, my work on *right brain-to-right brain nonverbal communication* describes the right-lateralized interbrain synchronization embedded in the mother-infant (and therapist-patient) relationship.

In my ongoing writings, I continue to offer an interpersonal neurobiological model of the ontogeny of intersubjectivity over the 1st years of human life (e.g., Schore, 2012a, 2019a, 2019b). The early substratum of this adaptive capacity is laid down in

the *prenatal period* and in the mutual regulating relationship between the fetus' and mother's physiological systems across the placenta. In the last trimester of pregnancy, this dyadic system is centrally involved in the fetal programing of the stress regulating hypothalamic-pituitary-adrenal axis. At this point in development, the paraventricular and ventromedial areas of the hypothalamus are activated in stress regulation, the right insula onsets its stress-responsive visceroautonomic functions, and the regulatory functions of the central and medial functions of the amygdala and their dense connections into the autonomic nervous system, come on line (Schore, 2017a).

During this same time, frame developing structures in the fetal brain support a critical period of growth of the rapidly maturing autonomic nervous system, what Jackson (1931) described as "the physiological bottom of the mind." Porges (2011) offers research evidence documenting that the early forming, oldest, parasympathetic unmyelinated dorsal nucleus of the vagus, the later developing catecholaminergic sympathetic nervous system, and the last developing and newest parasympathetic myelinated ventral vagal system in the nucleus ambiguus are functioning at the start of the last trimester. In discussing "the development of the autonomic nervous system in the human fetus," he concludes that "The unique features of the autonomic nervous system that support mammalian *social behavior* start to develop during the last trimester of fetal life" (p. 126, italics added). Underscoring the laterality of these ANS subsystems, he proposes a right-lateralized circuit of emotion regulation that supports the functional dominance of the right side of the brain in regulating autonomic function. Porges further states that the maturation of this ventral vagal system continues well into the first year.

In the ensuing perinatal postpartum stage after birth, the psychobiologically attuned mother and the neonate begin to co-create face-to-face communications that are driven by subcortical face processing areas. In body-to-body communications, the infant also processes olfactory stimuli that emanate from the mother's body. In previous writings, I have offered evidence that, in this earliest stage of postnatal development, a critical role is continued to be played by the central medial amygdala, with its deep connections into bioaminergic arousal centers in the midbrain and brain stem and the sympathetic and parasympathetic components of the autonomic nervous system (Schore, 2014b, 2017a, 2019a). In these primordial nonverbal communications, the mother regulates the infant's internal states of sympathetic and parasympathetic autonomic arousal, thereby facilitating a burgeoning state of autonomic balance and a subjective sense of safety, expressed in the infant's quiet alert state (Schore, 1994/2016). In classic writings, Basch (1976) stated that "the language of mother and infant consist of signals produced by the autonomic, *involuntary* nervous system *in both parties*" (1976, p. 766, italics added). Thus, these reciprocal bidirectional autonomic processes are expressed in involuntary and not voluntary motor behavior.

I suggest that the early postnatal stage of human development is a critical period for a transition from subcortical to cortical face processing systems and from the dorsal vagal to the experience-dependent maturation of the right-lateralized ventral vagal social engagement system of Porges (2011). With direct relevance to the precursors of intersubjectivity, Porges asserts "The right vagus and, thus, cardiac vagal tone are associated with processes involving the expression and regulation of motion, emotion, and communication" (p. 140), and that "the vagal control of the right side of the larynx produces changes in vocal intonation [prosody] associated with expression of emotions" (p. 141, italics added). According to Manini et al. (2013), "The autonomic nervous system seems to represent an elementary mechanism supporting emotional synchrony between mother and infant" (2013, p. 2). This maturational advance heralds the onset of mother-infant right hemispheric eye-to-eye, body-to-body left-sided cradling, an evolutionary facilitator of social cognition (Forrester et al., 2018; Schore, 2019a,b).

Indeed, at around 8 weeks, the onset of primary intersubjectivity, there is a dramatic progression of the infant's social and emotional capacities. This postnatal period is initiated in a critical period of development of the infant's posterior right cortical areas involved in sensory processing, the right insula and its autonomic connections, the right basolateral amygdala and its dense connections with cortical areas, and the medial frontal areas in the right anterior cingulate associated with responsivity to social cues (Schore, 2019a). Within episodes of mutual gaze, the most intense form of human communication, the intuitive mother's and infant's right brains engage in synchronized, spontaneous facial, vocal, and gestural communications of positive emotional states (see **Figure 1**). Such highly arousing, emotion-laden, and face-to-face interactions allow the infant to be exposed to high levels of social information. In these right brain limbic-autonomic emotional transactions, the mother makes herself contingent, easily predictable, and manipulatable by the infant, and thereby able to interpersonally synchronize her brain with her infant's developing brain.

Most intriguingly, research documents neuroplastic structural changes in the mother's brain during this same developmental period (Kim et al., 2010). This longitudinal study included two time points: 2–4 weeks postpartum and 3–4 months postpartum, and therefore over the onset of intersubjectivity, 2–3 months. During this period, gray matter in the mother's brain increases in specifically her right insula, hypothalamus, anterior cingulate, and amygdala, as well as in the reward-associated mesolimbic dopamine nuclei in the substantia nigra. The authors conclude that interactions with the infant induce these structural changes, which are expressed in functional increases of maternal motivation and sensitivity to infant cues. Indeed, they report "these structural changes at 3–4 months were predicted by a mother's positive perception of her baby at the first month postpartum. Thus, the mother's positive feelings for her baby may facilitate the increased levels of gray matter" (Kim et al., 2010, p. 698). This clearly implies that the mother's positive feelings for her developing baby are associated with subsequent changes in her own brain.

These infant and maternal neurobiological data can be interpreted within the framework of interpersonal neurobiology's central principles that the structure and function of the mind and brain are shaped by synchronized emotional relationships, and that brains align their neural activities in

social interactions. This simultaneous brain growth on both sides of the mother-infant dyad suggests an alignment between mother's and infants' right brain cortical-subcortical limbic circuits during positively-valenced intersubjective emotional protoconversations. At 2–3 months, a critical period for the onset of intersubjectivity, the mother's right basolateral amygdala and anterior cingulate are undergoing neuroplastic reorganization, at the very same time when her infant's right basolateral amygdala and anterior cingulate are in a critical period of growth. This coordinated accelerated synaptic growth in both brains *occurring at the same time* is another example of mother-infant synchrony defined as coordinated timing in development (Jaffe et al., 2001).

INTERSUBJECTIVE BIOENERGETIC TRANSMISSIONS GENERATE POSITIVELY CHARGED INTERBRAIN SYNCHRONIZATION

As mentioned, these episodes of "affect synchrony" occur in the first expression of social play. I suggest that these positively charged mother-infant emotional interactions generate increasing levels of dopaminergic arousal, and thereby joy (elation), a state of intense pleasure plus the urge for contact-seeking. Dopamine is the most important catecholamine involved in reward effects, and in this co-creation of a "reciprocal reward system" high levels of ventral tegmental mesolimbic dopamine are generated in both brains. Activation of the mesolimbic dopamine system that exerts a growth-promoting neurotrophic effect on the postnatal cortex is associated with initiation of movements to emotional or motivational stimuli, and the incentive of motivation and anticipation of reward (Schore, 1994/2016). Trevarthen also reported an increased positive state of excitement in protoconversations, which I suggest is associated with states of regulated sympathetic noradrenergic hyperarousal.

Stern (1990) described how infants seek stimulation that arouses, excites, and activates them and find this state of heightened activation intensely pleasurable. He described the energetic capacities of dynamic "vitality affects," the positive effects that are required to build self-structure and characterized maternal social behavior that can "blast the infant into the next orbit of positive excitation" (Stern, 1985). In such interactions of interpersonal resonance, both partners match states and simultaneously adjust their social attention, stimulation, and accelerating energy-mobilizing catecholaminergic sympathetic autonomic arousal to each other's responses. On a moment-to-moment basis, the empathic caregiver's sensory stimulation synchronizes with the crescendos and decrescendos of the infant's endogenous rhythms, allowing the mother to appraise the nonverbal expressions of her infant's internal emotional arousal and positive psychobiological states, to mutually upregulate them, and to communicate and intersubjectively share them with the infant.

In these essential face-to-face emotional transactions of mutual gaze, the mother initially attunes to and resonates with the infant's resting state but, as this state is dynamically activated (or deactivated or hyperactivated), she contingently fine tunes and corrects the intensity and duration of her affective stimulation in order to maintain the child's positive affect state. As a result of this moment-by-moment synchronized matching of affective direction both partners increase together their degree of engagement and facially expressed positive effect. This interactive microregulation continues, as soon after the "heightened affective moment" of accelerating arousal and an intensely joyful full gape smile the baby gaze averts in order to autoregulate the potentially disorganizing effect of the accelerating arousal of the intensifying emotional state. In order to maintain the positive emotion, the psychobiologically attuned mother takes her cue and backs off to reduce her stimulation. She then waits for the baby's signals for reengagement, signaled in the reappearance of the infant's quiet alert state (Schore, 2003a).

In this manner, not only the tempo of their engagement but also their disengagement and reengagement are coordinated and synchronized. In this process of contingent responsivity, "the more the mother tunes her activity level to the infant during periods of social engagement, the more she allows him to recover quietly in periods of disengagement, and the more she attends to the child's reinitiating cues for reengagement, the more synchronized their interaction" (Schore, 1996, p. 61). The psychobiologically attuned sensitive caregiver who is physiologically synchronized with the child thus facilitates the infant's emotional information processing by adjusting the mode, amount, variability, and timing of the onset and offset of stimulation to the infant's actual integrative capacities (Schore, 2003a).

In such synchronized, reciprocal, and turn-taking interactions, the mother must be attuned not so much to the child's overt behavior as to the reflections of the covert, involuntary physiological autonomic rhythms of his or her internal state, enabling the dyad to co-construct a "mutual regulatory systems of arousal" that contains a "positively amplifying circuit affirming both partners" (see Schore, 1994/2016 on "Mirroring gaze transactions and the dyadic amplification of positive affects"). The capacity of the infant to experience increasing levels of positive arousal states is thus amplified and externally regulated by the primary caregiver and depends on her capacity to playfully engage in synchronized emotional exchanges that generate increased positive arousal in herself and her child (see Figures 2.1 and 2.2 in Schore, 2003a).

I would add that this "interpersonal synchrony" is also expressed in right-lateralized "interbrain synchrony," simultaneous changes of emotional energy within the right brains of both members of the dyad, In terms of self-organization theory, the mutual entrainment of their right brains during moments of affect synchrony triggers an *amplified energy flow*, which allows for a coherence of organization that sustains more complex states of consciousness within both the infant's and the mother's right brains. Recall, the assertions of Trevarthen and Aitken (2001) in synchronized primary intersubjective transactions interpersonally resonated positive states of arousal are *amplified*, that this impacts the infant's capacity to generate "rudiments of individual consciousness," and that this two-person interpersonal context serves as a developmental origin of not only subjectivity but also "self-consciousness."

In parallel writings, Tronick et al. (1998) described the co-creation of an expanded "*dyadic state of consciousness*" within the mother-infant dyad, when the emergent state of consciousness becomes more coherently organized and more complex. Tronick hypothesized that "the capacity to create dyadic states of consciousness with another, and the quality of those states, depends in part on the history the individual had in creating these states early in development with his or her mother (and others)" (p. 298–299). He also proposed that dyadically expanded states of consciousness represent an "unconscious force driving social engagement" (1998 p. 296). In earlier works, I suggested that Tronick is describing an expansion of what Edelman (1989) called as "primary consciousness" that relates visceral and emotional information pertaining to the biological self to stored information processing pertaining to outside reality, which is specifically located in the right brain. Similarly, Trevarthen's "rudiments of individual consciousness" refer to this intersubjective right-lateralized primary consciousness within the infant's developing "right mind" (Ornstein, 1997). Right brain "primary consciousness" is thus communicated and generated in right brain-to-right brain "primary intersubjectivity." Note the intersubjective interbrain synchronization between two right-lateralized subjective minds, and its impact upon a cardinal function of a mind, the generation of states of consciousness.

Furthermore, Feldman et al. (2011) highlighted the relational context of "intense moments" of "interaction synchrony" co-created by 3-month old infants and their mothers:

> Face-to-face exchanges are short events spread across the daily routine of parent and child that mark purely social moments and involve *higher levels of positive arousal and social coordination*, as compared to episodes of caregiving and feeding. The brevity and intensity of such moments appear to initiate a process of biological concordance between the partners' heart rhythms. As seen, during episodes of high positive arousal – for instance, moments of vocal or affective synchrony which are accompanied by *high positive energy – the tightness of the biological synchronicity increased*…gaze synchrony in of itself…without a rise in positive arousal, did not increase biological synchrony (p. 573, italics added).

These emotional transactions involving synchronized ordered patterns of energy transmissions (directed flows of energy) represent the fundamental core of the right brain systems of communication and regulation (see Schore, 2003a, 2012a). Synchrony in dynamic systems, including social systems, is viewed as a complex, emergent, and indeterminate process. A central tenet of dynamic systems theory holds that at particular critical moments, a flow of energy allows the components of a self-organizing system to become increasingly interconnected, and in this manner organismic form is constructed in developmental processes. As the patterns of relations among the components of a self-organizing system become increasingly interconnected and well-ordered, it is more capable of maintaining a coherence of organization in relation to variations in the environment. This description applies to the interconnectivity of the cortical-subcortical components of the early developing right hemispheric subjective self-system.

More specifically, in right brain-to-right brain emotion-transacting intersubjective communications, organized patterns of information emanating from the caregiver's face, voice, and gestures trigger synchronous metabolic energy shifts in the infant's brain and body, central nervous system, and autonomic nervous system. The caregiver is thus modulating changes in the child's energetic state, since physiological arousal levels are known to be associated with changes in cellular metabolic energy. Within a co-created intersubjective field, these regulated emotional exchanges *between* the mother and infant in turn elicit synchronized increased energy shifts in both of their right brains. This right-lateralized interbrain synchronization generates dynamic vitality affects in a *co-created energized intersubjective field* also creates metabolic (mitochondrial) biological energy that facilitates the growth and developmental organization *within* the infant's rapidly growing brain, especially during critical periods of right brain development associated with a regional transition from anaerobic to aerobic metabolism (see "synchronized bioenergetic transmissions" in Schore, 1994/2016). This metabolic energy is imprinted into circuits of synaptic connectivity between the cortical and subcortical levels of the infant's developing right brain, allowing the emotion processing right brain to act as a dynamical system, a cohesively organized self-regulating *integrated whole*. In this manner, "the self-organization of the developing brain occurs in the context of a relationship with another self, another brain" (Schore, 1996, p. 60). This fundamental intersubjective mechanism of human development lies at the core of what Stern (1977) called as "the first relationship," and Brazelton and Cramer (1990) termed as "the earliest relationship" between the infant and another human being, the mother.

Indeed, throughout the life span energy shifts are the most basic and fundamental features of emotion, discontinuous states are experienced as affect responses, and nonlinear psychic bifurcations are manifest as rapid affective shifts. Such state transitions result from the activation of synchronized bioenergetic processes in central nervous system cortical and limbic circuits that are associated with concomitant homeostatic adjustments within the autonomic nervous system's catabolic energy-mobilizing sympathetic and anabolic energy-conserving parasympathetic branches. Furthermore, interpersonal physiological synchrony is expressed in the coupling of the sympathetic and parasympathetic components of the autonomic nervous systems *between* individuals. Physiologically synchronized and mutually regulated emotional mind-body states thus reflect the nonlinear pulsing of positively charged energy flows *within* the components of a dynamic, self-organizing right-lateralized mind-body system of the subjective self, as well as *between* one right-lateralized intersubjective self and another intersubjective self.

RIGHT TEMPOROPARIETAL CORTEX: A CENTRAL NODE OF THE SOCIAL BRAIN

In 1997, I published an article on the organization of the early developing right brain, in which I described the rapid, implicit,

and nonconscious emotional energy-dependent imprinting of regional cortical-and subcortical circuits during critical periods of infancy (Schore, 1997). Subsequent research confirmed the early development of the right brain, before the left (e.g., Gupta et al., 2005; Sun et al., 2005; Mento et al., 2010; Ratnarajah et al., 2013). Supporting the idea of an early period of accelerated growth at 2–3 months, research indicates that in the first 3 months brain growth increases by 64% (Holland et al., 2014), and that the total number of cortical neurons in the human brain increases by 23–30% from birth to 3 months (Shankle et al., 1999). In light of the well-documented observation that the onset of primary intersubjectivity occurs at 2–3 months, specifically what cortical right brain structures are in a critical period of growth and synaptic connectivity at this time? Since the infant's visual-facial, auditory prosodic, and tactile-gestural sensory processing occurs in the posterior cortical areas of the early developing right hemisphere, this right-lateralized posterior cortical region is such a candidate.

In previous writings, I reported extant developmental neurobiological studies of the infant brain showing that regional differences in the time course of cortical synaptogenesis exist, and that the metabolic activity that underlies regional cerebral function is ontogenetically highest in the posterior sensorimotor cortex and only later rises in anterior cortex (Schore, 1994/2016). In the first months of life association, areas of the posterior parietal (somatosensory) cortex mature as a result of high levels of *tactile* bodily sensation provided by the maternal environment, with visual input secondary (Chugani et al., 1987). Yamada et al. (1997) functional magnetic imaging (fMRI) research demonstrated a milestone for normal development of the infant brain occurs at about 8 weeks. At this point, in time a rapid metabolic change occurs in the primary visual cortex of infants. These authors interpret this rise to reflect the onset of a critical period during which synaptic connections in the occipital cortex are modified by *visual* experience. A more recent study documented a large, robust cerebral asymmetry in the infant right superior temporal cortex at 3 months (Glasel et al., 2011). These researchers suggest that this rapid growth is specifically associated with visual processing, voice perception, and nonverbal social communication.

With respect to the processing of *auditory* prosody, a near-infrared spectroscopy (NIRs) study by Homae et al. (2006) revealed that prosodic processing of a female emotional voice occurs in 3-month-old infants, specifically in the right temporoparietal region. Indeed, auditory information emanating from the mother's face, embedded in the affective tone of her emotionally expressive voice, is known to be processed in the right temporoparietal cortex (Ross, 1983). In discussing the mother-infant interaction, Dissanayake (2017) emphasizes how much all three sensory modalities or "languages" of the intersubjective engagement, facial, vocal, and body, are *processed as a whole* in the infant's brain during these interactions. The right temporoparietal junction (right TPJ) is known to be activated in the experiencing of *positive affect* associated with *synchronous multisensory stimulation* (Tsakiris et al., 2008).

This right-lateralized system, a heteromodal association area located at the intersection of the *posterior* end of the superior *temporal* sulcus, the inferior *parietal*, and the lateral *occipital* cortex *integrates* these three sensory modalities (the *voice*, and *touch* and *face* of the mother). Indeed, the right temporoparietal system *integrates* input from auditory, visual, somesthetic, and emotional limbic areas and forges critical period connections with the right ventral anterior cingulate involved in responsivity to social cues and play behavior, and the right insula with its extensive connections into the ANS that generates a representation of visceral responses accessible to awareness, thereby providing a somatosensory substrate for subjective bodily-based emotional states experienced by the corporeal self. The right TPJ forges direct synaptic contacts with the right basolateral amygdala and its extensive connections with cortical association areas, and the right-lateralized hypothalamico-pituitary-adrenocortical and sympathoadrenomedullary systems involved in autonomic activity.

During the early postnatal critical period of posterior cortical development, the right TPJ cortical-subcortical system also increases its reciprocal connections with the right ventral striatum and right ventral tegmental areas involved in mesolimbic dopaminergic positive arousal and reward, the right locus coeruleus that generates states of noradrenergic arousal and attention, and the right raphe nucleus associated with the serotonergic modulation of emotional and sensory reactivity (see Schore, 2019a,b). These three bioaminergic arousal-generating systems in the midbrain and brainstem continue to evolve in postnatal periods when they send axon collaterals up the neuraxis, thereby exerting trophic, energetic, and regulatory roles on the development of the cerebral cortex and limbic system (Schore, 2012a, 2019a). In total, this increased cortical-subcortical interconnectivity of the right TPJ cortical-subcortical sensoriaffective system allows for the infant's developing right brain to form more complex implicit visual-facial, auditory-prosodic, and tactile-gestural nonverbal communications, and thereby even greater capacities for intersubjectivity.

A large body of recent research now indicates that the functions of the right TPJ strikingly mirror the central functions of Trevarthen's primary intersubjectivity. Recall his description of the interpersonal context of protoconversation: face-to-face, interactively synchronized, reciprocal, and rhythmic-turn-taking social interactions embedded in an intersubjective nonverbal communication system that evolves in intimate free play and co-creates a positive affective relationship and interpersonal awareness between mother and infant (see **Figure 1**). Researchers are emphasizing "the importance of the right temporoparietal junction in collaborative social interactions" (Tang et al., 2016, p. 23) and are documenting its fundamental involvement in the building of positive relationships (Kinreich et al., 2017).

Interdisciplinary studies now document that this posterior right cortex, a central node of the social brain (Santiestaban et al., 2012), is activated in face-to-face transactions (Redcay et al., 2010), where it functions in "attention and social interaction" (Krall et al., 2015, p. 587) in a social context of a "basic interpersonal interaction" (Goldstein et al., 2018, p. 2532). The right TPJ serves as a convergence zone of sensory and contextual information, which is then integrated to create

a social context with other social agents (Lee and McCarthy, 2016). This multifunctional system is centrally involved in updating one's internal model of the current environment (i.e., contextual updating) and adjusting expectations based on incoming sensory information (Geng and Vossel, 2013). It responds to visual, auditory, and tactile stimuli (Matsuhashi et al., 2004) and is specialized for the detection of personally relevant stimuli, particularly when they are salient or unexpected (Corbetta and Shulman, 2002).

Furthermore, authors are now asserting that this right hemispheric temporoparietal polysensory area "plays a key role in perception and awareness" (Papeo et al., 2010, p. 129) and, in "the unconscious guidance of attention," "*outside of conscious awareness*" (Chelazzi et al., 2018, p. 2, italics added). This right-lateralized implicit system is involved in "the control of self-and other representations" (Santiestaban et al., 2012, p. 2274) and in the ability to "switch between internal, bodily, or self-perspective and external, environmental, or other's viewpoint" (Corbetta et al., 2008, p. 317). This posterior area of the right hemisphere is also a pivotal neural locus for multisensory body-related information processing (Decety and Lamm, 2007, p. 580), and for "maintaining a coherent sense of one's body" and a "subjective feeling of body ownership" (Tsakiris et al., 2008). These latter authors observe that this structure generates "an *internal model of the body* that would function as a stored template against which to compare *novel* stimuli, playing a role in maintaining a basic sense of *embodied self*" (p. 3015, italics added).

In seminal studies, Decety and Lamm (2007) wrote on the central role of the right temporoparietal junction in *social interaction and self-functions*, and in another Decety and Chaminade (2003) concluded that "self-awareness, empathy, identification with others, and more generally intersubjective processes are largely dependent upon…right hemisphere resources, which are the first to develop" (p. 591). Indeed, this right-lateralized system is known to be fundamentally involved in face and voice processing, as well as "making sense of another mind" (Saxe and Wexler, 2005, p. 1391). The dynamic intersubjective interaction of one right temporoparietal system with another right temporoparietal system in a collaborative social interaction is thus expressed in a face-to-face right brain-to-right brain nonverbal communication embedded in an intersubjective protoconversation.

Note the remarkable complexity of the subjective and intersubjective functions of the right TPJ cortical-subcortical system in the early postnatal period. As mentioned these adaptive, indeed essential primordial psychobiological functions include a developing ability to engage in nonverbal emotional communications with another human being and share a positive emotional state, a responsiveness to social relational cues, a capacity to integrate sensoriaffective stimuli, and the detection of personally relevant stimuli particularly when they are salient or unexpected, as well as perception, attention, awareness, consciousness, and a representation of an embodied self. These recent discoveries in neuroscience underscore the central importance of this right-lateralized system in human development. Yet, I suggest that this early appearing psychic structure that *operates outside of conscious awareness* has previously extensively described by Sigmund Freud, and that its adaptive functions lie at the core of psychoanalytic theory.

Utilizing a neuropsychoanalytic perspective, I deduce that the multifunctional right temporoparietal system is isomorphic with Freud's early developing unconscious corporeal ego. In *The Ego and the Id*, Freud (1923/1961) concluded that "The ego is first and foremost a *bodily ego*." Freud spoke of an early developing unconscious ego and a later developing conscious ego, which "is in control of voluntary movement" and is "located in the speech area on the left-hand side" (Freud, 1923/1961), clearly alluding to the posterior regions of the left hemisphere and Wernicke's receptive language area, and what neuroscientists are now describing as a "verbally driven ego-bound mode of ordinary consciousness" (Flor-Henry et al., 2017). Yet, Freud also stated "A part of the ego – and heaven knows how important a part – may be unconscious, undoubtedly is unconscious" (Freud, 1923/1961). He further asserted "The processes in the Ego (they alone) may become conscious. But they are not all conscious, nor always so, nor necessarily so; and large parts of the Ego may remain unconscious indefinitely" (Freud, 1926/1961).

These neuropsychoanalytic data suggest that the early developing coherently organized unconscious ego is neuroanatomically located in the right brain, the psychobiological substrate of the unconscious mind. They indicate a significant modification of Freud's theory – this right posterior cortical-subcortical system is involved in not only intrapsychic but also interpersonal functions of a relational unconscious that intersubjectively communicates with another relational unconscious. In optimal interpersonal contexts, at 2–3 months the human bodily-based unconscious ego can nonverbally communicate with another unconscious ego *via* intersubjective, synchronized, and reciprocal right temporoparietal-to-right temporoparietal social-emotional interactions. Furthermore, science now documents that the earliest expression of the human unconscious mind is not a Freudian intrapsychic cauldron of untamed passions and destructive wishes but an interpersonal generator of amplified joy and shared love. On the other hand, this research confirms Freud's fundamental discoveries, demonstrating that this right-lateralized system of social connectedness, a deep core of the personality, operates implicitly, beneath awareness as an unconscious ego in everyday life, across the life span. These findings underscore the fact that the human unconscious, a central construct of psychodynamic theory and clinical practice for the past 100 years, needs to be reinserted into academic developmental psychology from which it has almost been banished.

THE DEVELOPMENT OF INTERSUBJECTIVITY OVER THE 1ST YEAR AND BEYOND

During the 2–3 month transitional period of the human brain growth spurt, new adaptive functional advances of the rapidly maturing right brain emerge, including the capacity to

intersubjectively emotionally communicate with other minds, and the ability to share intense emotional states with another human being. In classic developmental research, the psychoanalyst-psychiatrist Stern (1985) described the transition from an early forming "emergent self" at birth into a "*core self*" at 2–3 months, the exact interval of Trevarthen's primary intersubjectivity. He observed, "At the age of 2–3 months, infants begin to give the impression of being quite different persons. When engaged in social interaction, they appear to be more wholly *integrated*. It is as if their actions, plans, affects, perceptions, and cognitions can now all be brought into play and focused, for a while, on an interpersonal situation" (p. 69, italics added). Stern noted that with the onset of this emergent developmental function, the subjective social world is altered and interpersonal experience operates in a different domain, a domain of "core-relatedness." He concluded that at this developmental stage, the infant participates in shared "observable interactive events" involved in "bridging the infant's subjective world and the mother's subjective world" (p. 119), and that now "There are many ways being with an other can be experienced…such as merging, fusion…symbiotic states" (p. 100). I suggest that these early evolving intersubjective functions of the core self are associated with the infant's developing right temporoparietal self-system,

In their research on the 2–3 month transition, Ammaniti and Gallese (2014) reported that

> From the second month after birth, parents and infant begin to show a temporal structure in their interactions… In this period, the sharing of social gaze between parent and baby is the expression of coordinated [synchronized] interactions, which can occur between 30% and 50% of the time. At the same time, mutual gaze can be integrated with parents' and infants' affectionate touch… At around 3 months, parents tend to touch their baby in an affectionate way and infants tend to respond with an intentional *affectionate touch* (p. 147, italics added).

Note the increases of the mother's loving touch that emerge at this time period.

Confirming this same transitional critical period Miall and Dissanayake (2003) documented changes in the mother's behaviors:

> Over time, mothers subtly adjust their sounds and movements to what the baby seems to want (or not want), and to its changing needs and abilities. They gradually move from the gentle, cooing reassurance of the first weeks to trying to engage the baby in increasingly animated *mutual play*. At 8 weeks utterances and facial expressions have become more *exaggerated*, both in time and space (2003, p. 342, italics added).

Dissanayake (2017) also described prosodic motherese as dyadic in nature, where both partners influence each other, and multimodal, where multiple senses are involved. Frame-by-frame microanalyses of videotaped mother-infant interactions showing the faces and torsos of both partners side-by-side reveal that facial expressions and head-and-body movements are as significant in the interaction as vocalizations (Murray and Trevarthen, 1985).

In another study of the co-created positively valenced nonverbal communication system between mother and infant that evolves in this same time period, Dissanayake (2001) asserted that

> It should also be emphasized here that although mothers 'talk' to their babies, the multimodal messages in early interactions are nonverbal. What mothers convey to infants are not their verbalized observations and opinions about the baby's looks, actions, and digestion—the ostensible content of talk to babies—but rather positive affiliative messages about their intentions and feelings: You interest me, I like you, I am like you, I like to be with you, You please me, I want to please you, You delight me, I want to communicate with you, I want you to be like me (p. 91).

In the intimate context of *intense positive affect*, these are the first nonverbal communications of maternal love. The Oxford English Dictionary defines love as "*deep* affection, *strong* emotional attachment."

In very recent writings, I have described how Trevarthen's primary intersubjectivity evolves in an intimate context of interpersonally synchronized *mutual play*, a shared positive affective relationship that amplifies *intense* joy and excitement, and that this same *intimate* context of maternal affection also interactively generates the *strong emotions* of *mutual love* (Schore, 2019a,b). In those volumes, I suggest that the loving mother's and infant's right brain-to-right brain intimate playful nonverbal communications generate high levels of accelerating amplified positive emotional arousal, which fundamentally is known to be associated with changes in metabolic energy. The emotional energy embedded in this intense positive affective state of deep affection of mutual love is available to the infant's developing right brain while exposed to high levels of spontaneous interpersonal and intrapersonal novelty, allowing for the multimodal integration of external and internal sensations.

In this manner, the energized intersubjective field of mutual love structuralizes Stern's "core self" that appears at 2–3 months, a critical period of right brain development, and thus the core self, operating at levels beneath conscious awareness, has an enduring influence on the capacity to co-create an emotional loving bond with a valued other at later stages of the life span. Ammaniti and Gallese (2014) offered an evocative portrayal of Stern's model of the similar interpersonally synchronized expressions of mutual love in early and later development:

> As Daniel Stern has written, expressions of love begin early in an astonishing way. Mother and child behavior overlaps with the behavior of two lovers. For example, mother and child look at each other without speaking, hold a physical closeness with faces and bodies in constant contact, display alterations in vocal expressions or *synchrony of movements*, and perform particular

> gestures like kissing each other, hugging, touching, and taking the face or the hands of the other… When parents speak to their child, or lovers talk with one another… they emphasize the musicality of the words instead of the meaning, they use baby talk, and they express a wide range of nonverbal vocalizations… Facial expressions assume a special register also, altering and emphasizing the facial mimic. There is also a choreography in the movements of mother and baby, like those of two lovers; *they move in synchrony, getting closer and more distant on the basis of a common rhythm* (pp. 110–111, italics added).

For an interpersonal neurobiological model of the capacity for mutual love, I refer the reader to my chapter "The development of the right brain across the life span: what's love got to do with it?" (Schore, 2019a).

Authors are now asserting that, over the 1st year, "intersubjective behavior continues to grow significantly over the semesters" (Muratori et al., 2011, p. 19). The synchronized right brain-to-right brain mother-infant intimate playful intersubjective protoconversation continues over human infancy in mutual play, songs, lullabies, and nursery rhymes. In peek-a-boo episodes, maternal affect matches, synchronizes, and amplifies infant joy. A mother playing peek-a-boo will delay the removal of her hands from her eyes in order to provoke amusement and laughter from her baby or similarly when reciting "This Little Piggy" will wait to utter what the fifth piggy squeals – "wee, wee, wee, all the way home." Recall, the right temporoparietal system responds to visual, auditory, and tactile stimuli and the detection of personally relevant stimuli, particularly when they are *salient or unexpected*. In this early mutual play, repetition in the mother's exaggerated facial expressions, vocal utterances, and body movements and the effect of surprise coordinates and synchronizes the minds and brains of two bodies, mutually regulating the infant emotionally and uniting mother and child temporally (see Schore and Marks-Tarlow, 2018). Thus, over the course of the 1st year, *intersubjective play* occurs in a relational context of what Tronick (2007) terms "mutual regulation."

The perspective of interpersonal neurobiology suggests that mother-infant play is more socioemotional than cognitive, and that, fundamentally, the underlying mechanism of this arousal-altering, pleasurable, rewarding mutual activity facilitates the experience-dependent maturation of right brain cortical and subcortical systems. This primordial form of intersubjective play generates the neurobiological substrate on which all forms of play evolve – mother-infant and solitary, spontaneous and controlled, and active and passive (see Schore, 2017b interview in the *American Journal of Play*). During the 1st year, intersubjective synchronized mutual play expands the infant's affect array and facilitates the dyadic amplification and transformation of mildly pleasurable enjoyment into joy and the intensification of mildly pleasurable interest into excitement. At 10–12 months, the onset of a critical period for the right orbitofrontal cortex and the emergence of upright locomotion, fully 90% of maternal physical and verbal behavior consists of affection, play, and caregiving, and by 1 year of age, curiosity and stimulation-seeking exploratory play time increases to as much as 6 h of a child's day (Schore, 1994/2016).

My colleague Meares (2016, p. 52) asserts "the mother-infant protoconversation represents an interplay between two right brains." He argues that in optimal developmental contexts, the right brain-to-right brain protoconversation continues in the second year, a time when a toddler develops a burgeoning playful imagination and shows an expanded need for novel experiences. With the ongoing expansion of higher right brain functions, the intersubjective protoconversation takes the form of intersubjective imaginative games, then intrasubjectively internalized dialogs, and finally what Meares calls "conversational play." This creative game, which the toddler plays while alone, is grounded in the child's burgeoning capacity for make-believe and is expressed in the expressive use of emotional words and analogy. Indeed, Meares describes it as right hemispheric analogical or protosymbolic play, which is imbued with the affective dimension of joy and pleasure. The creative game consists of a miniature story, told as if to the child himself or herself but also to someone else, who is not there except as a feeling of the background presence of the internalized, protoconversational mother. This earliest form of symbolic play allows the toddler to play with ideas and generate fantasies, including fantasied interactions with other minds (Schore, 2017b). Furthering these ideas, I would add that, upon entering early childhood, these products of the emergent imagination can also be shared with a valued other in the intersubjective play of creative storytelling.

The psychoneurobiological substrates of symbolic play and imagination, heavily influenced by right brain activation, emerge at the end of the human growth spurt, late in the second year (Dobbing and Sands, 1973). These two right-lateralized adaptive functions, plus another, mutual love, are higher right brain functions built upon a shared common lower-level processes, primary intersubjectivity and protoconversation, which onset at the beginning of the right brain critical period. In this manner, the interpersonally synchronized right brain-to-right brain intersubjective communications that begin to structuralize the right temporoparietal core self at 2–3 months represent the primordial developmental crucible of the adaptive capacities of mutual play, love, and imagination (see Schore, 2019a,b). These fundamental expressions of humanness can be accessed not only *within* a mind but also intersubjectively shared *between* human minds.

The right hemisphere continues to enter into growth spurts in the later stages of development (particularly adolescence), and so the right-lateralized synchronized intersubjective communication system can continue to evolve across the life span. Throughout life interpersonal synchrony, operating beneath levels of awareness, acts as a fundamental interpersonal neurobiological mechanism not only within *dyads*, but also in all human *group* dynamics, and in the organization of all *cultures* (Schore, 2012b, 2020). That said it should be pointed out that the well-documented time frame of the primordial critical period for intersubjectivity is not protected in the United States, which is the only industrialized country that has no maternal

leave policy, leading many mothers to re-enter the work force at 6 weeks and put the child into day care, before the 2–3 month transition even begins. This lack of legislated temporal protection for the establishment of the foundations of a loving maternal-infant relationship may in turn have long-term effects on the emotional health of the culture, especially on males, whose right brains mature more slowly than females, making them more vulnerable to early relational stressors and susceptible to developmental disorders and externalizing psychopathologies (Schore, 2012b, 2017a, 2019a).

CONCLUSION: INTERSUBJECTIVITY AS RIGHT BRAIN-TO-RIGHT BRAIN COMMUNICATIONS: UPDATE AND CLINICAL APPLICATIONS

In the prior sections of this work, I described how the posterior right temporoparietal system is centrally involved in synchronized nonverbal communications. This adaptive function of the early forming core self is expressed in adulthood as a capacity to enter into intersubjective, reciprocal, right brain-to-right brain nonverbal interactions with another human, beneath the words. Recall previously cited research demonstrated "the importance of the right temporoparietal junction in *collaborative social interactions*" in a social context of a "*basic interpersonal interaction*." In her recent research, Feldman et al. now assert that "brain coordination may be supported by the *non-verbal* rather than verbal aspects of social interactions" and that "brain-to-brain synchrony localizes to temporal-parietal regions, and highlight the role of attachment and social connectedness in the coordination of two brains" (Levy et al., 2017, p. 6, italics added). These descriptions clearly imply a shift from a one-person intrapsychic to a two-person interpersonal psychology, and a "two-person," "two-brain" technology that can simultaneously measure two brains interacting in real time.

Toward that end, in the last decade, hyperscanning methodologies utilizing simultaneous electroencephalography (EEG), fMRI, magneto-encephalography (MEG), and near-infrared spectroscopy (NIRS) measurements have been created. In pioneering work, Montague et al. (2002) stated "studying social interactions by scanning the brain of just one person is analogous to studying synapses while observing either the presynaptic neuron or the postsynaptic neuron, but never both simultaneously" (p.1160). This technological advance now allows for a deeper understanding of a spontaneous social interaction between two dynamically synchronized, nonverbally communicating brains, including face-to-face, moment-to-moment right brain-to-right brain emotional communications at levels beneath awareness. The "ultrarapid" unconscious detection of a human face takes place in just 100 ms (Crouzet et al., 2010).

Inspired by the developmental research on sensitivity of social contingency in infants and mothers that used two synchronized video cameras (see earlier references), Dumas et al. (2010) offered a now classic dual EEG hyperscanning study of interbrain synchronization during a spontaneous social interaction between two adults, characterized by reciprocal nonverbal communication and turn-taking (a central feature of primary intersubjectivity). This methodology utilized a simultaneous measurement of brain activities of each member of a dyad during interpersonal communications, where "both participants are continuously active, each modifying their own actions in response to the continuously changing actions of their partner" (Dumas et al., 2010, p. 1). In this relational context, both share attention and compare cues of self and other's actions. These researchers documented specific *changes in both brains* during nonverbal imitation, a central foundation of socialization and communication.

Dumas et al. described the interbrain synchronization, on a milliseconds time scale, of the right centroparietal regions, a neuromarker of social coordination in both interacting partners (Tognoli et al., 2007) and synchronization between the right temporoparietal cortex of one partner and the right temporoparietal cortex of the other. Citing Decety and Lamm (2007), they pointed out that the right temporoparietal junction is known to be activated in social interactions, attention orientation, self-other discrimination, and the sense of agency. The top-down view of **Figure 2** shows this interbrain synchronization lateralized to the right hemisphere of each member of a communicating dyad. Note that the figure depicts specifically right-lateralized interbrain synchronization, and what I have called a reciprocal right brain-to-right brain nonverbal communication system. This dynamic synchronized right TPJ-to-right TPJ "basic interpersonal interaction" operates "outside of conscious awareness (Chelazzi et al., 2018) as a "two-person unconscious" (Lyons-Ruth, 1999), a relational unconscious nonverbally communicating with another

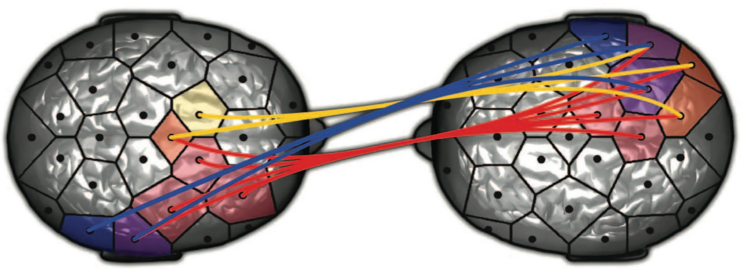

FIGURE 2 | Top-down view of a right-lateralized interbrain synchronization of a co-created spontaneous nonverbal communication system. From "Toward a Two-Body Neuroscience" by Dumas (2011). Permission by Dumas.

relational unconscious. In turn, this intersubjective interaction between the mind of one subjective self and another subjective self co-creates an emotionally-energized intersubjective field between them (Schore, 1994/2016, 2003a,b, 2012a, 2019a,b).

For three decades, my work on right brain-to-right brain nonverbal communication has described the critical role of intersubjectivity in the co-created mother-infant and therapist-patient relationship (Schore, 1994/2016, 2003b, 2012a, 2019a). Recall the description of Trevarthen (1993) of protoconversation occurring between "minds in expressive bodies" (p. 126). There is a long tradition in psychoanalytic psychotherapy that conceptualizes intersubjectivity as an unconscious interaction between the mind of the clinician and the mind of a patient (Benjamin, 2017; Yakeley, 2018). With an emphasis on the patient's subjective experience, the focus is on changes in emotional and relational functions expressed in the therapeutic relationship, the product of the interaction of the patient's mind/body and the therapist's mind/body. Due to the current intense interest of both researchers and clinicians in early development in the primacy of affect, and in "implicit" (unconscious) phenomena that operate below levels of awareness, not only psychodynamic but also all forms of treatment now stress the role of rapid emotional communications between the minds of both members of the therapeutic alliance. This intersubjective context of nonverbal communication allows the patient and the empathic clinician to "make sense of another's mind."

Like the developmental process of attachment, intersubjectivity is now seen as a critical construct within psychotherapy. Although Trevarthen stressed the role of intersubjectivity in positively charged play states, psychotherapists also address the nonverbal intersubjective communications of negatively valenced and even traumatic emotional states (Schore, 2009, 2013). Indeed, early stressful ruptures of the attachment bond that are routinely not followed by relational repair are commonly found in patients with an early history of right brain attachment stressors. In my ongoing work, I continue to offer clinical and interdisciplinary research evidence demonstrating that all psychiatric disorders show deficits in right brain affect regulation, and that the right hemisphere is dominant in psychotherapy (Schore, 1994/2016, 2003b, 2012a, 2014a, 2019a).

There is now general acceptance that intersubjective relational deficits as well as affect dysregulation are a central focus of all forms of infant, child, adolescent, adult, and group psychotherapy (see Schore, 1997, 2000, 2002, 2003b, 2019b, 2020). In terms of the dyadic psychotherapeutic relationship, right brain deficits of intersubjectivity are expressed in an inability, especially under relational stress, to nonverbally emotionally communicate and interpersonally synchronize with another brain (e.g., see Schore, 2014b for deficits of intersubjectivity in autism spectrum and severe attachment disorders). It has long been established that stress is defined as an asynchrony in an interactional sequence, and thus "a period of synchrony, following the period of stress, provides a 'recovery' period" (Chapple, 1970, p. 631). Synchronized rupture and repair of the emotional attachment bond between the patient and therapist is thus an essential interpersonal neurobiological mechanism of the treatment (Schore, 1994/2016, 2003b, 2012a, 2019b). In addition to the patient's symptomatology, these intersubjective difficulties lie at the core of the treatment of the patient's relational deficits that operate outside of conscious awareness.

Toward that end, I continue to offer current neuroscience data and clinical material to describe how the co-created psychotherapeutic relationship acts as an intersubjective social context of spontaneous reciprocal nonverbal emotional communications of face, prosody, and gestures within the emerging therapeutic alliance (Schore, 2012a, 2019a). These dynamically synchronized moment-to-moment, right brain-to-right brain communications of emotional self-states between two minds take place in the present moment, a time frame of fractions of a second to 2–3 s. In recent writings on physiological synchrony in psychotherapy, Tschacher and Meier (2019) assert "Synchrony is generally defined as the social coupling of two (or more) individuals in the here-and-now of a communication context that emerges *alongside, and in addition to, their verbal exchanges*" (p. 558, italics added). This right-lateralized *nonverbal* psychobiological system, operating beneath levels of conscious awareness, intersubjectively synchronizes with another "emotional" right brain *that is tuned to receive these right brain-to-right brain communications*, clearly implying that, when working with the patient's dysregulated emotions, the empathic clinician needs to transiently shift dominance from the explicit left brain to the implicit right brain. In recent research on "right hemispheric dominance in nonconscious processing," Chen and Hsiao (2014) demonstrate that the left hemisphere plays a greater role in processing explicit knowledge, whereas the right hemisphere has an advantage in shaping behavior with implicit information.

In "heightened affective moments" of a psychotherapy session, the intuitive therapist implicitly "surrenders" into a callosal shift from the left hemispheric posterior temporoparietal system in Wernicke's receptive language area that processes grammatical processing, semantic knowledge, and syntax in verbal conversations, to the right hemispheric posterior temporoparietal system that intersubjectively processes nonverbal emotional protoconversations. The key clinical ability of the empathic psychobiologically attuned therapist is not to intellectually understand the patient but to emotionally listen to and subjectively feel the patient. This transient reversal of hemispheric dominance allows the "open and receptive" clinician, in an implicit state of "therapeutic presence" and "wide-ranging," "evenly-suspended," and "free-floating attention" to listen beneath the patient's words (see Schore, 2019b). This therapeutic intersubjective context allows the empathic therapist to emotionally *recognize* the patient and enables the patient's right brain subjective self to emotionally experience *feeling felt* by the therapist (Schore, 1994/2016, 2012a, 2019a). In this manner, the emotionally sensitive therapist, *from the first point of contact in the first session*, is implicitly learning the nonverbal moment-to-moment rhythmic structures of the patient's internal states and is relatively flexibly and fluidly modifying her own behavior to synchronize with that structure, thereby co-creating an interpersonal context for the organization of the right brain-to-right brain therapeutic alliance.

In the clinical literature, Meares (2012) directly refers to Trevarthen's intersubjective protoconversation and asserts that the dynamic "interplay between two right brains provides a structure for the therapeutic relationship" (p. 312). Face-to-face interpersonal synchronization of right brain patterns enables the therapeutic dyad to intersubjectively communicate and implicitly share their conscious *and* unconscious emotional states in what I have termed "a conversation between limbic systems," a "spontaneous emotion-laden conversation" (Schore, 2012a). This right-lateralized interpersonal neurobiological mechanism allows the clinician to act as an interactive regulator of the patient's emotional states, which in turn facilitates a reduction in the patient's presenting symptomatology. In this work, the clinician interactively downregulates negative effect in stress-reducing therapeutic contexts and upregulates positive effect in playful therapeutic contexts.

From the perspective of modern attachment theory (Schore and Schore, 2008) patients' organized and disorganized attachment styles refer not only to different implicit strategies of emotion regulation, but also to different abilities for entering into intersubjective synchronized right-lateralized nonverbal emotional communications with others. These essential right brain functions are expressed in the therapeutic relationship, and thereby available for change. Indeed, the therapeutic working relationship co-created by the patient and therapist has long been known to be a major vector of psychotherapeutic change processes. In a recent special issue of the journal *Psychotherapy* entitled "Evidence-based psychotherapy relationships," the editors Norcross and Lambert (2018) assert, "decades of research evidence and clinical experience converge: the psychotherapy *relationship* makes substantial and consistent contributions to outcome independent of the treatment" (p. 313, italics added). More than mastering techniques the skilled therapist is an expert in working directly with right brain emotions and interpersonal relationships. For clinical applications of regulation theory to working in the co-constructed relationship between the patient and therapist, especially within stressful rupture and repair interactions, I refer the reader to my latest clinical volume, *Right Brain Psychotherapy* (Schore, 2019b).

Very recent technological advances in neuroscience now allow for a deeper understanding of the interactions of two right brain systems in the therapeutic *relationship* or working alliance. Psychotherapy researchers are also now using functional near-infrared spectroscopy (fNIRS) hyperscanning, a non-invasive, safe, portable, low-cost imaging modality in order to study the brains of both patients and therapists during face-to-face psychotherapy in the research laboratory (Zhang et al., 2018). Citing previous studies showing interpersonal synchrony in the right temporoparietal junction during a collaborative face-to-face interaction (Tang et al., 2016), and in a context of social connectedness (Kinreich et al., 2017), their methodology also included subjective measures of the "bond or positive personal attachments" within the working alliance, that represent "the connection between client and counselors."

During the 40-min session the therapeutic dyad discussed moderately stressful "developmental issues" and "interpersonal relationships" and focused on "the client's emotional states or personal troubles." These investigators document better working alliances and increased interbrain synchronization in specifically the right temporo-parietal junction between clients and counselors during the *first session* of *psychological counseling*. This effect was not found when they were just chatting. They conclude that this work supports an interpersonal synchrony model of psychotherapy, which dictates "the more tightly the client and counselor's brains are coupled, the better the alliance" (Koole and Tschacher, 2016, p. 7). The authors further suggest that this interbrain synchronization of the temporoparietal system in the patient's and therapists' right brains plays an important role in building a positive relationship in the emerging therapeutic alliance. The authors point out that fNIRS is only able to detect changes in cortical blood flow, and thus it cannot probe subcortical structures, specifically mentioning the amygdala, insula, and anterior cingulate medial frontal cortex that are synaptically connected with the right temporoparietal cortex. That said fMRI studies during live face-to-face social interaction shows "greater activation in brain regions involved in social cognition and reward, including the right temporoparietal junction, anterior cingulate cortex, right superior temporal sulcus, ventral striatum, and amygdala" (Redcay et al., 2010, p. 1639).

In a more recent publication, this laboratory offers another fNIRS hyperscanning study of interactive brain synchronization during the interpersonal communication process within the first psychotherapeutic session, specifically exploring the role of the counselor's experience in building a therapeutic alliance with the client (Zhang et al., 2020). The work addresses the widely accepted clinical principle that an effective therapeutic relationship or working alliance is the most common and essential therapeutic factor in the clinical and counseling literatures (Wampold and Imel, 2015), and that the establishment of an effective therapeutic relationship is an essential component of therapeutic expertise (Hill et al., 2017). Toward that end, experienced counselors with an "integrative orientation" based on more than one theoretical psychotherapeutic orientation and 600–4,000 h of clinical experience were compared with novice counselors in terms of a capacity for interpersonal brain synchronization.

These authors describe how in the face-to-face therapeutic context of the psychotherapy session reciprocal intersubjective communications represent an interpersonal context in which both members observed each other nonverbal cues, facial expressions, and gestures. Significant increases in interpersonal brain synchronization were especially evident when the clinician had more psychotherapy experience. They report that in the session the clinician's ability to specifically focus on emotional states and to interpersonally synchronize with the client is an expression of therapeutic expertise, and that interpersonal brain synchronization is therefore an essential "*nonverbal skill* to help to improve the working alliance" (Zhang et al., 2020, p. 103, italics added). The authors also note that "experienced psychotherapists reported that they used moment-to-moment cues (e.g., emotional expression and body postures) and tried to be attentive to their clients reactions" and conclude that "expert/experienced counselors must be able to adapt to different types of clients, as well as being responsive and collaborative" (p. 8). Importantly, they again document that, during the session

synchronous brain activity was seen in specifically the right temporoparietal junction of both members of the therapeutic dyad, *the exact same right-lateralized interpersonal brain synchronization and intersubjective right brain-to-right brain communication as the Dumas pattern in* ***Figure 2***.

It should be noted that the intersubjective motivational system and the attachment motivational system are both central mechanisms involved in psychotherapeutic change, and that both are involved in adaptive right brain interpersonal neurobiological functions. Developmentally, the former system, located in the right temporoparietal regions and its subcortical connections enters a critical period of maturation at the beginning of the 1st year, while the latter, located in the right orbitofrontal regions and its more extensive cortical and subcortical connections, at the end of the 1st year (Schore, 1994/2016, 2003a,b, 2012a, 2019a,b). In the second year, the posterior right temporoparietal cortical areas form reciprocal bidirectional synaptic connections with the anterior right orbitofrontal cortical areas, the hierarchical apex of the limbic system and the locus of the attachment control system and the most complex affect and stress regulating mechanisms, thereby allowing the right brain to act as an integrative self-regulating system.

The psychobiologically simpler early maturing right-lateralized intersubjective system of reciprocal nonverbal *communication* between two right minds structurally and functionally evolves at the beginning the human brain growth spurt, in contrast to the more complex later maturing right-lateralized system of *regulation* of emotional states that structurally and functionally evolves at the end of the growth spurt. Throughout the life span the early developing capacity of intersubjectivity acts as a right-lateralized nonverbal *positive* emotion *communicating* and *mutually regulating system*, while the later maturing attachment system builds upon the intersubjective system and functions as an adaptive right brain regulation system that can *self-regulate and interactively regulate* positive *and* negative emotions. Thus, I have described how interactively regulated affect transactions that maximize positive and minimize negative affect cocreate a secure attachment bond between mother and infant. The construct of interpersonal synchrony is a central communicational element of both right brain intersubjective protoconversation and attachment dynamics. The evolutionary mechanism of attachment fundamentally represents the regulation of biological synchronicity between *and* within organisms. These dual right brain processes underly the right-lateralized subjective self's capacity for *communicating* with other minds, intersubjectivity, as well as for attachment, interactively *regulating* emotion between and within brains, minds, and bodies.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, and further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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Sharing Experiences in Infancy: From Primary Intersubjectivity to Shared Intentionality

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We contrast two theses that make different assumptions about the developmental onset of human-unique sociality. The primary intersubjectivity thesis (PIT) argues that humans relate to each other in distinct ways from the beginning of life, as is shown by newborns' participation in face-to-face encounters or "primary intersubjectivity." According to this thesis, humans' innate relational capacity is the seedbed from which all subsequent social-emotional and social-cognitive developments continuously emerge. The shared intentionality thesis (SIT) states that human-unique forms of interaction develop at 9–12 months of age, when infants put their heads together with others in acts of object-focused joint attention and simple collaborative activities. According to this thesis, human-unique cognition emerges rapidly with the advent of mind-reading capacities that evolved specifically for the purpose of coordination. In this paper, we first contrast the two theses and then sketch the outlines of an account that unifies their strengths. This unified account endorses the PIT's recognition of the fundamental importance of primary intersubjectivity. Any act of sharing experiences is founded on the communicative capacity that is already displayed by young infants in primary intersubjectivity. At the same time, we question the PIT's interpretation that dyadic encounters have the triadic structure of joint attention. Lastly, we draw on empirical work on the development of joint attention, imitation, and social referencing that serves as evidence that primary intersubjectivity continuously unfolds into the capacity for triadic joint attention.

Keywords: primary intersubjectivity, shared intentionality, the second person, social cognition, social development, social understanding

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Human infants reciprocally engage with others from the first few weeks of life. By 6–8 weeks old, they make eye contact, smile at, and summon their partner with cooing vocalizations in face-to-face encounters (Stern, 1977, 1985; Reddy, 2003, 2008, 2011; Trevarthen, 2011). The ability of infants to communicate in this way has been called "primary intersubjectivity" (Trevarthen, 1979). Illustrative descriptions of primary intersubjectivity come from Stern (1977, 1985, 1990), Trevarthen (1979, 1993, 1998), Bråten (2009), Bråten and Trevarthen (2007), Field et al. (1985), Field and Fogel (1982), Cohn and Tronick (1988), Tronick et al. (1978), Reddy (2008, 2011), and others. The following exchange recorded by Stern (1977, p. 3) between a mother and her 3-month-old while nursing exemplifies infants' other-orientation and expressiveness in primary intersubjectivity.

> *[. . .] the mother turned her head and gazed at the infant's face. He was gazing at the ceiling, but out of the corner of his eye he saw her head turn toward him and turned to gaze back at her. This had happened*

before, but now he broke rhythm and stopped sucking. He let go of the nipple and the suction around it broke as he eased into the faintest suggestion of a smile. The mother abruptly stopped talking and as she watched his face begin to transform, her eyes opened a little wider and her eyebrows raised a bit. His eyes locked on to hers, and together they held motionless for an instant. The infant did not return to sucking and his mother held frozen her slight expression of anticipation. The silent and almost motionless instant continued to hang until the mother suddenly shattered it by saying "Hey!" and simultaneously opening her eyes wider, raising her eyebrows further, and throwing her head up and toward the infant. Almost simultaneously, the baby's eyes widened. His head tilted up and, as his smile broadened, the nipple fell out of his mouth. Now she said "Well hello! …. heelló… heeelloóoo!," so that her pitch rose and the "hellos" became longer and more stressed on each successive repetition. With each phrase the baby expressed more pleasure, and his body resonated almost like a balloon being pumped up, filling a little more with each breath. The mother then paused and her face relaxed. They watched each other expectantly for a moment. The shared excitement between them ebbed, but before it faded completely, the baby suddenly took an initiative and intervened to rescue it. His head lurched forward, his hands jerked up, and a fuller smile blossomed. His mother was jolted into motion. She moved forward, mouth open and eyes alight, and said, "Oooooh… ya wanna play do ya… yeah?… I didn't know if you were still hungry…. no… nooooo…. no I didn't…" And off they went.

This instance illustrates how both adult and infant contribute to the exchange by taking turns and rhythmically coordinating their responses (Brazelton et al., 1974; Condon and Sander, 1974; Murray and Trevarthen, 1986; Isabella and Belsky, 1991; Rochat et al., 1998; Rochat and Striano, 1999; Bråten, 2009; Trevarthen, 2011). Before much was known about dyadic interaction in great apes, it was speculated that humans inherited the capacity for intersubjectivity from primate ancestors (e.g., Bruner, 1982; Tomasello, 1999). Today's primatological record, however, suggests that apes do not show the same kind of mutual other-orientation that characterizes primary intersubjectivity (Gómez, 1996, 1998; Kano et al., 2012, 2018; Carpenter and Call, 2013). Although non-human primates also pay attention to their conspecifics' faces, they focus less on the eyes than humans do, and, more importantly, do not hold eye-to-eye contact, smile, coo, or make rhythmic movements toward one another (Kano and Tomonaga, 2010; Kano et al., 2012; Grossmann, 2017; Kano and Call, 2017; but see Myowa, 1996, and Ferrari et al., 2006, for reports about mimicry and Bard, 2012, for emotional engagement). There is therefore broad consensus today that primary intersubjectivity is uniquely human (Bruner, 1995; Hobson, 2004; Tomasello, 2019; Bjorklund, 2020). There is, however, disagreement about whether young infants' "protoconversations" (Trevarthen, 1979) with others or whether instead later-developing social-cognitive skills define human sociality and mental development.

Some, most notably Reddy and colleagues, have suggested that primary intersubjectivity is not just essential for social bonding but that it is the source from which all social knowledge and understanding springs (Kaye, 1982; Reddy, 2003, 2008, 2015). In this view, human life is distinctly intersubjective and dialogical from the beginning (at least 2 months onward), and it is this innate intersubjective orientation that defines our human nature. Later forms of sharing experiences that go beyond the dyadic encounter between you and I are, in this account, extended versions of an original "inter-human consciousness" (Rödl, 2021) that is already present in primary intersubjectivity. Call this the primary intersubjectivity thesis (PIT). A different view has been put forth by Tomasello and colleagues in their shared intentionality theory, according to which human-unique sociality develops through a cognitive revolution at 9–12 months of age, when infants engage in new behaviors of joint attention, imitative learning, and cooperative action (Tomasello et al., 2005; Moll and Tomasello, 2010; Tomasello, 2018, 2019). In this view, the kind of social relatedness that defines us as a species–because it transforms the individual intentionality we inherited from our primate ancestors–is one in which our attention to each other is mediated by an object of shared attention or interest, some third entity toward which we orient together. This transformation is enabled by the development of recursive mind-reading processes ("I understand that you want me to attend to x") that form the cognitive basis of shared intentionality, including joint attention, cooperative communication, and similar cooperatively structured interactions. Call this the Shared Intentionality Thesis (SIT).

The aim of this article is to build a bridge between the PIT and the SIT. There has been relatively little crosstalk between the two theses' proponents, although they share the goal of tracing human-unique sociality to its roots. The SIT has tended to overlook the development of triadic relations from earlier, dyadic, intersubjective relations. More specifically, it has not sufficiently acknowledged that the "sharing" of triadic joint attention is accounted for by the same intersubjective awareness that is already in play when 2-month-olds smile, coo, and express affect in primary intersubjectivity. At the same time, we think that Reddy (2008, 2011), today's main defender of the PIT, has overstated what primary intersubjectivity entails. She suggests that face-to-face encounters between young infants and their caregivers already have the triangular shape of joint attention because the infant experiences herself as the object to which she and her partner are attending. We believe that there is little evidence that young infants mentally step outside of the relation that unites them with the other by considering how they are being perceived by the other. We also think that construing primary intersubjectivity as a compressed version of triadic joint attention underestimates the change that occurs when infants engage in actual, triadic, joint attention (with an object external to self and other), with its ramifications for social learning, perceptivity, and theory of mind.

But there is a tendency toward integration of the two theses. The SIT's ambition is to deliver a comprehensive developmental and evolutionary account of all forms of human-unique relatedness. The SIT has therefore assigned primary intersubjectivity, since its human-uniqueness has been established, a firm place in its theoretical framework as an initial milestone in humans' ontogenetic pathway of social cognition (Tomasello et al., 2005). Young infants' sharing of emotions is argued to serve the purpose of social bonding—a mechanism that is recognized to underly "virtually all forms of uniquely

human cooperation and shared intentionality" (Tomasello, 2019, p. 31). The SIT has also modified its evolutionary narrative, the 'interdependence hypothesis', to better account for the communicative capacities of even young infants (Tomasello and Gonzalez-Cabrera, 2017).

We want to suggest further integration of what we see as the two theses' strengths: The PIT's recognition of the fundamental importance of dyadic human interchange in early infancy and the SIT's emphasis of the novel quality of later-developing triadic joint attention. Such a hybrid account is not new; it has been suggested by the work of Adamson and Bakeman (1982, 1984), Striano and colleagues (Striano and Rochat, 1999; Striano and Bertin, 2004; Striano and Stahl, 2005) and Hobson (2004). Here, we wish to revive it and give further evidence in its support. In the next part of this article, we articulate on what points we see the PIT and the SIT as differing. In the last part, we discuss some problems of each thesis and broadly sketch the outlines of an account that unifies their strengths.

1. WHERE THE PIT AND THE SIT DIFFER

We isolate three issues on which the PIT and the SIT differ (see **Table 1**). The first issue concerns the age at which infants first share experiences with other persons intersubjectively. The PIT maintains that even newborns share experiences with others, whereas the SIT argues that intersubjective sharing begins at 9–12 months. The second difference deals with the issue of whether primary intersubjectivity already has the triadic structure that characterizes joint attention. The PIT affirms this whereas the SIT negates it. The third issue concerns the problem of whether early social-cognitive and social-emotional development is continuous or discontinuous. The PIT states that primary intersubjectivity continuously unfolds into object-centered forms of joint attention over the course of the first year of life. The SIT, by contrast, claims discontinuity, with a sharp onset of joint attention at 9–12 months.

We shall stress that the PIT's take on the second and third issue represent the ideas of Reddy (2008, 2011). Stern and Trevarthen, pioneers in the study of infant intersubjectivity, do not share Reddy's views on these issues. They both proclaimed discontinuous social development (Stern, 1985, spoke of "quantum mental leaps") and defined a level or layer of sociality—the "intersubjective self" (Stern, 1985) and "secondary intersubjectivity" (Hubley and Trevarthen, 1979), respectively—that corresponds in timing of onset and content with the SIT's shared intentionality. These authors thus do not claim that dyadic person-to-person engagement already contains all the essential elements of triadic engagement or that the latter is a mere spatial extension of the former. We chose to portray Reddy's ideas on these matters because hers contrasts most clearly with the SIT's and has informed recent empirical investigation (Rossmanith et al., 2014).

TABLE 1 | Three issues on which the Primary Intersubjectivity Thesis (PIT) and the Shared Intentionality Thesis (SIT) differ.

Issue	PIT	SIT
Onset of capacity and motivation to share experiences	By 2 months (primary intersubjectivity)	At 9–12 months (shared intentionality)
Is primary intersubjectivity triadic?	Yes	No
Continuous or discontinuous development	Continuous	Discontinuous

We draw on the work of Reddy (2008, 2011) for our representation of the PIT's view on the second and third issue. Reddy's thoughts on these issues do not reflect those of other scholars of primary intersubjectivity, such as Stern (1985) or Trevarthen (1978), Hubley and Trevarthen (1979).

1.1. Sharing Experiences: When Does It Begin?

For the PIT, dyadic encounters like the one captured by Stern (1977) prove that within 2 months post birth, infants have remarkable relational capacities; they are ready to communicate and share experiences with others. This contradicts the idea that infant and caregiver initially form an undifferentiated bundle from which the infant first needs to separate herself. There is no such task of self-other differentiation, as Stern (1985, p. xiii) notes: "the infant's major developmental task is the opposite one, the creation of ties with others—that is, increasing relatedness." The PIT's idea is that newborns experience themselves as separate subjects who turn to others in order to create social ties (Rochat, 2011; Rochat and Robbins, 2016; Tasimi, 2020, p. 2). Support for the view that young infants perceive themselves as separate and long for subject-to-subject interchange can be seen in their preference for *high but imperfect* social contingency (Watson, 1972; Murray and Trevarthen, 1986; Gergely and Watson, 1996, 1999; but see Marian et al., 1996). Their preference for highly contingent interaction indicates that they want to engage with subjects like themselves because it is others of their kind that can provide such contingent responses (Meltzoff and Gopnik, 1993; Meltzoff, 2007). Neonatal imitation, if it exists (see Oostenbroek et al., 2016, 2019, and Meltzoff et al., 2018, 2019, for a debate), would provide further and even earlier indication that newborns recognize others as similar and yet different subjects. Infants' rejection of perfectly contingent responses further demonstrates that they do not want to be confronted with a mirror image but strive to interact with someone who is recognizably "other" or different from themselves.

How important positively-toned, rhythmic, exchanges with other humans are for young infants is revealed by how emotionally perturbed they become when their partner abruptly disengages and by the concerted effort they make to reanimate her (Tronick et al., 1978, 1982; Nagy et al., 2017). According to the PIT, all of this shows that even newborns connect with other minds and are aware of others' subjectivity. As Trevarthen and Aitken (2001, p. 4) claim, "the infant is born with awareness specifically receptive to subjective states in other persons."

The SIT acknowledges that by 2 months of age, infants engage in a kind of "emotion sharing" that helps them and their parent become affectively attuned. But the SIT denies that these exchanges are intersubjective because the infant does not yet recognize others as intentional agents and subjects of experience. Tomasello writes, "Some researchers, especially Trevarthen,

believe that these early interactions are 'intersubjective,' but in my view they cannot be intersubjective until infants understand others as subjects of experience—which they will not do until 9 months of age" (1999, p. 60). Different criteria are thus invoked to decide if an exchange qualifies as intersubjective. Whereas Trevarthen regards 2-month-olds' participation in protoconversations as sufficient proof that they understand others' subjectivity, thus making the exchange intersubjective, Tomasello demands proof that infants understand self and others as intentional agents. A prerequisite for understanding intentionality, according to him, is that infants experience themselves as instrumental agents, which they begin to do around 8 months of age when they differentiate means from ends in goal-directed activities (Piaget, 1953; Frye, 1991). By 9 months, infants are aware that others are also subjects of intentional and goal-directed action (Woodward, 1998; Cannon and Woodward, 2012)—a realization they allegedly develop by an "argument" from analogy (Tomasello, 1999). Once infants recognize others' intentionality, their motivation and skill for intersubjective sharing sets in. This manifests in a suite of joint attentional behaviors, all of which are said to emerge at 9–12 months (Carpenter et al., 1998). These include:

- perceiving objects together by seeing or hearing them simultaneously or in quick succession and looking back to the partner (e.g., Adamson and Bakeman, 1985; Butterworth and Jarrett, 1991)
- gesturing deictically to objects or events in order to share them (e.g., Liszkowski et al., 2004)
- imitative learning, i.e., re-enacting another's action in recognition of "doing the same" (Hobson and Hobson, 2007)
- turning to other persons as guides by orienting to them when confronted with novel situations (social referencing; e.g., Campos and Stenberg, 1981)
- playing one's part in simple collaborative projects or games with shared goals, such as simple games of give and take (e.g., Carpenter et al., 2005; Tomasello and Carpenter, 2005)

Many of these behaviors are shown just for the sake of sharing, which infants, so long as they do not have autism, find rewarding (Kasari et al., 1990; Gómez et al., 1993; Gangi et al., 2014; Siposova and Carpenter, 2019). Other behaviors are performed to get another to do something (imperative pointing) or to learn how to handle an unfamiliar situation (social referencing).

In their longitudinal study of infants between 9 and 15 months, Carpenter et al. (1998) found that these skills emerge rapidly, are correlated with one another and are all in place by 12 months. The SIT explains the simultaneous development of joint attentional behaviors with a common psychological cause: a socially recursive mind-reading mechanism ("I understand that you intend for me to share this goal/perception") that adapts infants for mental coordination with other persons, especially adults (Tomasello et al., 2005; Tomasello and Gonzalez-Cabrera, 2017; Tomasello, 2019). The new social-cognitive mechanism has a dual-level structure that represents both the sharedness of the goal and the individuality of the roles and perspectives of the participants (Tomasello, 2019, 2020). In this picture, genuine intersubjectivity begins with a new form of relational thinking that transforms great ape intentionality into the capacity to knowingly act as part of a plural subject (a "we") in the context of joint attention, cooperative communication, and collaborative action. Only now is there a "meeting of minds" (Bruner, 1995) because only now do infants understand others as subjects of individual and shared experience.

As work by Mundy and others has shown, such a meeting of minds is difficult to realize for infants with autism spectrum disorder because their natural proclivity to establish joint attention is impaired. The greater the impairments in joint attention, the more severe the symptoms of the disorder tend to be (Sigman et al., 1986; Kasari et al., 1990; Mundy et al., 1994). Deeper investigations into the problem of joint attention in autism revealed the importance of breaking joint attention down into the mechanisms of *responding* to others' bids for joint attention (RJA) vs. *initiating* joint attention (IJA). It is particularly the latter capacity, IJA, that is defective in autism (Mundy et al., 2007). These clinical observations dovetail with the SIT's view that triadic joint attention characterizes human social cognition and is decisive for healthy, species-typical, development.

1.2. The Object Within: Is Primary Intersubjectivity a Case of Joint Attention?

One of the PIT's main charges against the SIT is its fixation on joint attention *to objects outside of the dyad*, i.e., to physical things other than the interaction partners themselves (Reddy, 2011, p. 141). Reddy (2003, 2008, 2011) argues that we have to look for the first objects of joint attention within the dyad itself, not at a distance. According to her, infants' understanding of the aboutness or object-directedness of attention begins in primary intersubjectivity. The 2-month-old is aware that she is the object of her interaction partner's attention. She experiences the other's gaze on her: "the infant feels the other attending to the self, the infant experiences the relation between looker and object" (Reddy, 2011, p. 144). The encounter with another human is thus the birthplace of self-awareness as much as it is the birthplace of other-awareness. Infants express their budding self-awareness in coy smiles, shy reactions, and other signs of (proto-)embarrassment like looking down or turning away when others look at them. This would imply that primary intersubjectivity is not just a two-place relation connecting you and I, but a three-place relation, with "me" as the object of your individual or our joint attention (I-You-Me). Reddy assumes that the third pole that characterizes joint attention is already present in what is typically thought of as just a dyadic, person-to-person, encounter.

Reddy (2008) thus believes that infants already understand others' intentional states, including their attentional states, by 2 months of age. There is no reason, according to her, to limit our interest to cases of joint attention with distal targets, as the SIT does. Rather than waiting for infants to refer to objects outside of the dyad, we should look for joint attention within the dyadic exchange, in which the infant experiences herself as the target of the other's attention. Primary intersubjectivity has the same object-directedness and therefore the same triangular shape as do cases of joint attention with external referents.

The SIT denies that primary intersubjectivity is a triadic relation or a form of joint attention (Tomasello et al., 2005). Face-to-face interactions between young infants and others are dyadic, not triadic, because they have no topic. There is no common project, goal, or object of interest that unites the participants. There is nothing over which two minds come together. But such a common topic, focus, or goal is what joint attention is all about: that two people knowingly co-orient toward something in the world. In primary intersubjectivity, I orient toward you, and you orient toward me. We are in mutual attention and what you do affects me and vice versa, but there is no shared goal, perception, or action. For the SIT, joint attention serves the purpose of mental coordination that is necessary for joint agency, which is made possible by socially recursive mental processes in which we both have the other as cooperative partner in mind. This enables effective collaboration and communication, including knowledge transmission between generations (Tomasello, 2019). Primary intersubjectivity, although it brings the other psychologically closer to me, does not support cooperative action because it does not bring the world into our shared view. Primary intersubjectivity and triadic joint attention are thus distinct phenomena.

1.3. Continuity or Discontinuity?

The PIT argues that social understanding unfolds continuously throughout infancy. Intersubjective attention sharing can be observed in infants as young as 2 months, marking the beginning of gradual growth in human social understanding. What changes over time are the objects of shared attention and the means by which they are shared. As stated in the previous section, Reddy (2008, 2011) argues that 2-month-olds experience themselves as objects of their interaction partner's attention. At 4 months, infants direct the other's attention to their bodies by calling on the other to repeat physical games such as tickling. By 6 months, infants are believed to sense when the other is attending to particular parts of their body (e.g., their feet) or to particular actions they perform (e.g., kicking). From around 7 months, infants direct and manipulate the other's attention by clowning, showing off, and teasing (Reddy, 1991). From 9 months onward, distal targets are rendered into objects of joint attention by way of holding them up, showing, vocally referencing or pointing to them. By 15 months, infants refer to absent entities, such as objects that are typically present but currently missing from the indicated location (e.g., an empty jar). All the while, the infant not only responds to others' bids for attention (RJA) but also initiates joint attention (IJA), to revoke Mundy's distinction of two dissociable processes (Mundy and Newell, 2007).

In support of the continuity claim, Reddy and colleagues conducted a microanalytic study (see Kaye, 1982, for microanalysis) on the development of joint book reading between mothers and their young infants (Rossmanith et al., 2014). Even 3-month-olds are said to have shown nascent abilities to jointly attend to books with their caregiver. What gradually changed with age were the modes of sharing and which aspect of the books was brought into focus. After manually exploring the books' materiality, the dyads shifted their attention to the pictures and their symbolic content, to which infants started to refer gesturally and vocally. The authors infer that, "rather than appearing suddenly supposedly mediated by a newly emerging capacity for joint attention these changes can be seen as part of a gradual development [. . .] coming out of the interplay of multiple strands of development in interaction with the social and cultural environment and the entire ecology of the activity" (p. 18). A similar interpretation is suggested by a dynamic systems perspective that highlights how infants' expanding sensorimotor repertoire (e.g., decoupling of hand and eye movements) and parents' continual adjustments to these changes drive the formation of joint attention and its changes over time (Deák and Triesch, 2006; Triesch et al., 2006; Deák et al., 2013; de Barbaro et al., 2013). The PIT sees this as evidence that joint attention does not suddenly spring into existence by means of a social-cognitive revolution between 9 and 12 months. There are no breaks, leaps, or revolutions in the development of joint attention: *natura non-facit saltus*. A problem that defenders of the SIT would see with these studies is that they leave open whether the infant in fact experienced the interactions with the object as shared. Because no communicative expressions such as sharing looks were reported, this crucial question is left unanswered. And because the studies involve no experimental manipulation of the social setting, it also remains uncertain how infants' object engagement was affected by their partner's actions. In the next section, however, we will report experimental data (surveyed, e.g., by Hoehl and Striano, 2013) that corroborate the PIT's continuity claim.

The SIT acknowledges that protoconversations between young infants and their caregivers are "deeply social in that they have emotional content and turn-taking structure" (Tomasello, 1999, p. 59), and that they serve to create a sense of connectedness and attunement. In a recent iteration of the SIT, Tomasello concedes that affective exchanges between infant and parent are "foundational to virtually all forms of uniquely human cooperation and shared intentionality" (Tomasello, 2019, p. 31). However, these early dyadic exchanges are, in this account, not underpinned by the same psychological infrastructure that supports the joint attentional skills of 9–12-month-olds (Tomasello, 1995). This infrastructure emerged/emerges rapidly both in evolution and ontogeny. A "radically new psychological process" (Tomasello, 2019, p. 15) is said to have transformed the minds of *homo* about 400,000 years ago, just like it transforms the minds of every generation of modern human infants as they are approaching their first birthdays. Overall, the SIT grants that primary intersubjectivity marks a crucial first step in the ontogeny of human-unique social development, but it rejects the idea of a continuous path leading from dyadic intersubjectivity to triadic joint attention. For the SIT, triadic joint attention at 9–12 months is a new phenomenon with a unique social-cognitive base (Tomasello, 1995). Triadic joint attention, not dyadic face-to-face interaction, is responsible for infants' introduction into the world of culture and is therefore principally involved in those processes of cultural transmission and cultural evolution (imitation, pedagogical learning etc.) that define our human nature.

2. TOWARD A UNIFIED ACCOUNT: FROM DYADIC INTERACTION TO TRIADIC ENGAGEMENT

We now sketch an account that integrates insights from the PIT and the SIT. It is the PIT's merit to have generated persuasive evidence that even young infants participate in reciprocal, dialogical exchanges with others. There is, we think, no reason to deny the intersubjective quality of these exchanges. However, we resist Reddy's attempt to collapse the third pole of triadic joint attention into dyadic infant-caregiver exchanges. We believe that the SIT is right in insisting that primary intersubjectivity is dyadic and that joint attention is a qualitatively different, triadic, relation. There is no convincing evidence that the infant in primary intersubjectivity contemplates the other's perception of herself and has anything further than just the other in mind. At the same time, studies on the development of joint attention, imitation, and social referencing have challenged the SIT's view that the transition from dyadic to triadic engagement occurs as a sudden leap at 9–12 months and instead suggests a gradual process in the second half of the first year of life. We now turn to these issues one by one in the following subsections.

2.1. Human Other-Orientation and Its Significance for Development

The PIT has convincingly shown that young infants are remarkably relational and other-oriented. Primary intersubjectivity is the first empirical demonstration of the fact that humans are a relational or transactional species. As Rödl (2014) puts it, humans are, as a species, "one toward another." He argues philosophically that humans' mutual other-orientation is logically prior to their ability to act as a dual or plural subject. What scholars of primary intersubjectivity have shown empirically is that humans' mutual other-orientation is temporally prior to dual or plural agency as well. Before infants can form a "we" with others and engage in joint attention and joint action, they first must recognize and address others as "you" in dyadic exchanges. Buber (1924) articulates this idea when he remarks that "in the beginning is relation"—with "relation" being his term for the dyadic encounter.

The SIT recognizes the fundamental importance of protoconversations as an important first step for infants and caregivers to bond. As mentioned, the SIT added a corollary to its evolutionary narrative, the "interdependence hypothesis," such that the emergence of primary intersubjectivity in hominin infants is now intelligible as an adaptation to a cooperatively organized breeding system (Tomasello and Gonzalez-Cabrera, 2017). In its older version, the hypothesis stated that selective pressures to develop collaborative foraging strategies explain the emergence of joint intentionality in human phylogeny and ontogeny. But because infants cannot participate in collaborative hunting, the early onset of the joint attentional capacities subserving such acts seemed mysterious (Hrdy, 2009, 2016). To account for this problem, the new version of the hypothesis argues that humans evolved special social skills not only in response to pressures to create collaborative hunting methods but also cooperative breeding practices. Within this adjusted theoretical framework, the expressive and communicative skills even of young modern infants can be explained by the advantage of eliciting care and attention from their multiple caregivers (Tomasello and Gonzalez-Cabrera, 2017).

But despite these adjustments, the SIT has not fully acknowledged the primacy of humankind's dyadic nature or mutual other-orientation, as is shown by its denial that young infants' exchanges with others are intersubjective. Tomasello's (1999) requirement that infants must be instrumental agents who also attribute instrumental agency to others seems too strong. It is not clear why instrumental agency should matter for the recognition of others as subjects, and why it should not suffice that young infants express a desire for socially contingent interaction with others of their kind (Brazelton et al., 1974).

The SIT emphasizes that joint attention is not the sum of two coinciding acts of attention but a single act of two who know of the jointness of their endeavor: the sharedness of their experience is open between them or mutually transparent (Taylor, 1985; Eilan et al., 2005; Gilbert, 2007; Zahavi, 2015; Siposova and Carpenter, 2019). To confirm that infants engage in joint attention, researchers look for "sharing looks" and "knowing smiles" (Hobson and Hobson, 2007; Carpenter and Liebal, 2011), which are precisely those communicative means infants in primary intersubjectivity deploy to signal their relatedness to their partner. In short, it seems that what puts the sharing into joint attention is the same mutual other-orientation that is already in play in primary intersubjectivity (see also Hobson and Hobson, 2011). We thus agree with the PIT that intersubjectivity is present within mere weeks after birth and that the other-orientation even young infants display in dyadic encounters is what allows for the sharing of experiences in joint attention.

2.2. Primary Intersubjectivity Is Dyadic, Not Triadic

Here we critically evaluate Reddy's (2003, 2008, 2011) analysis of primary intersubjectivity as an early form of joint attention. Reddy states that the young infant is not just attending to her interaction partner but that she is simultaneously aware of being the object of her partner's attention. In this conception, the infant's self is doubled: she is subject ("I") and object of experience ("me"). The infant's awareness of the other's gaze on her is expressed in alleged responses of shyness and coyness (Reddy, 2011, p. 146). This interpretation is, in our mind, overly complex, and infants' other-oriented attention in primary intersubjectivity does not, we think, warrant the interpretation that their attention is flexed back onto themselves in the way Reddy argues.

Reddy cites Buber's (1924) I-Thou mode of engagement in the context of her descriptions of primary intersubjectivity. But Buber in fact stresses that the other is *not* available as an object of empirical experience in an I-Thou encounter. The I-Thou forecloses any kind of objectification of one another because both participants, in Buber's view (1924), give themselves to the other entirely so that each has no object in front of them. If the infant experienced herself as the object of another's attention, she would not stand in an I-Thou relation à la Buber, but she would

figure as "it" in what Buber calls the I-It mode of engagement. Reddy's description of how the infant feels the other's gaze on her is more in line with Sartre's idea that self-awareness is born from the embarrassment or shame we feel when we sense that we have been detected or exposed (Zahavi, 2014). But the one who detects and exposes us, even if only in our imagination, is someone who looks at us from a detached perspective, not someone we encounter in mutual recognition (I-You). It thus seems impossible to preserve the I-You character of primary intersubjectivity while also arguing that the infant experiences herself as object of another's attention. We believe it is mistaken to point to humans' embodiment or corporeality (Leiblichkeit) and argue that when humans encounter each other, their mutual attention is mediated by their awareness of being physical objects of attention for one another, thus turning the encounter from a two-place relation into a "three-or-more-place" relation.

According to our more straightforward interpretation, primary intersubjectivity is a dyadic encounter in which infants reach out to a person communicatively with the goal to connect with her, subject-to-subject. There is nothing triadic about this because, as Hubley and Trevarthen (1979, p. 58) write, "this type of interaction is devoid of interest in events or objects in the external situations, or in the activities of either or both partners on objects." This leaner interpretation is not only more compatible with Buber's view of the human encounter that Reddy wants to endorse. It also reflects more accurately infants' unrefracted other-orientation, rather than preoccupation with themselves, during primary intersubjectivity.

The dyadic exchanges between infant and parent are open to being structurally enriched and expanded into triadic relations over time, allowing for the introduction of objects to which infant and adult attend together, "however slightly these objects are detached from the child's self" (Werner and Kaplan, 1967, p. 43).

2.3. Turning Together to the World: The Importance of Triadic Joint Attention

One effect of the PIT's interpretation of primary intersubjectivity as joint attention is the underestimation of actual triadic joint attention and its role as a difference-maker for the child's cognitive development, including language learning, (other forms of) imitative learning, theory of mind, and collaborative action. Longitudinal studies have revealed that joint attention at age 1 predicts concurrent and later language proficiency, both in typically-developing toddlers (Tomasello and Todd, 1983; Tomasello and Farrar, 1986; Kristen et al., 2011; Salo et al., 2018) and in those with autism (Mundy et al., 1990, 2007). Joint attentional capacities at 1 year also predict positive social outcomes, such as social competence in toddlerhood (Van Hecke et al., 2007). Skillful participation in joint attention is furthermore related to theory of mind development. Sodian and Kristen-Antonow (2015) found that declarative pointing at 1 year old predicts belief understanding at age 4.5 years. Similar correlations between joint attentional abilities in the second year and theory of mind at 3 and 4 years have been reported for both typical-developing children (Nelson et al., 2008) and children with autism (Charman et al., 2000).

Moll and colleagues found that infants in the second year who shared objects with others in joint attentional engagement could later discern which objects were (and were not) familiar to the other person. This discriminatory capacity collapsed, however, if infants did not share their experience of the objects (Moll et al., 2007, 2008), suggesting that joint attention is a *sine qua non* for infants' budding understanding of others' experiences. Consistent with this empirical work, philosophers have argued that triangulation with a mutually engaged other is necessary for the acquisition of the concepts of subjective belief and objectivity (Davidson, 1990; Verheggen, 1997).

There is no indication that these empirical and conceptual connections between triadic joint attention on one hand and language, perspectively, and an understanding of other minds on the other are reducible to the influence of primary intersubjectivity. To our knowledge, no correlations with later language development, perspectivity, and theory of mind have been shown to exist for primary intersubjectivity in the first few months of life. One might counter that the absence of such evidence cannot be interpreted as evidence of absence because studies do not go far back enough in time to include measures of dyadic engagement. Prospective studies on language development, joint attention, and theory of mind indeed rarely involve assessments of face-to-face interaction in early infancy. Our conjecture is that even if such measures were included, associations with later social-cognitive milestones might be difficult to find because primary intersubjectivity shows relatively little variation in timing of onset and—at least initially—in frequency, both between dyads and between cultures (Stern, 1977; Wörmann et al., 2012).

Further indication that the movement from dyadic to triadic interaction is key for healthy cognitive development comes from Williams Syndrome. Children affected by this disorder are highly interpersonally engaged and sociable (Jones et al., 2000; Järvinen-Pasley et al., 2008). They are very motivated to initiate and sustain I-You relations, as their strong inclination to make eye-to-eye contact, smile, and show other affiliative behaviors indicates. And yet, their cognitive development is noticeably impaired, as is shown by atypical and delayed language acquisition (Laing et al., 2002), deficits in visuospatial cognition (Frangiskakis et al., 1996; Gray et al., 2006) and overall cognitive functioning (Howlin et al., 1998). A viable hypothesis is that these shortcomings stem at least in part from a deficit in transitioning from dyadic attention (I-You) to object-oriented joint attention (I-You-It). Indeed, reduced abilities to respond to and initiate joint attention have been observed in young children with Williams Syndrome (Klein-Tasman et al., 2007; Järvinen-Pasley et al., 2008). Data from developmental psychopathology thus also suggest that joint attention yields benefits that cannot be reduced to effects of dyadic, face-to-face, interaction.

To sum up, there is persuasive developmental and clinical evidence that being capable and motivated to triangulate with others around objects and events is critically important for children's development across cognitive domains. Although social development begins with infants' drive to connect with others face-to-face, a crucial further step is needed to benefit from one's social connectedness and learn from

others about the world. Joint attention seems to be its own form of sharing experiences—one that builds on primary intersubjectivity without "being contained in miniature within [this] earlier constructed foundation" (Adamson and McArthur, 1995, p. 210). This affords a development whereby infants and their partners are no longer just mutual attenders but become co-attenders who knowingly shift their attention to external objects together. Infants need to loosen their grip on others in exclusively dyadic bouts of mutual attention and learn to relate to others as co-attenders with whom they bring the world into shared view.

2.4. Continuous Growth: From Dyadic Encounters to Triadic Joint Attention

We now review developmental studies of joint attention, imitation, and social referencing which indicate that, rather than emerging suddenly by way of a "9-months revolution" (Tomasello, 1999, p. 61), these capacities might develop in a more gradual fashion, such that a continuous path from infants' early dyadic to their later triadic relations with others can be traced.

Infants, from around 5–6 months on, slowly express a greater interest in the physical surround. They now often like to be held or carried facing outward, into the world, rather than chest against chest, and their motor capacities allow for the manual exploration of objects (von Hofsten and Rönnqvist, 1988). Importantly, however, these initial explorations of the physical environment occur in others' company rather than solo, and there is strong indication that they are informed by infants' preceding intersubjective awareness. That infants indeed in the first year of life, and prior to the alleged watershed of 9 months, bring their intersubjective competence to bear on their interactions with objects is suggested by cross-sectional and longitudinal research.

Cross-sectionally, Cleveland et al. (2007) conducted a set of experiments in which an adult either looked back and forth between an object and the infant (Joint Attention Condition) or looked back and forth between the object and the ceiling (No Joint Attention Condition). Subsequently measured looking times suggested that 7- and 9-month-olds processed the object more deeply in the Joint Attention Condition than in the No Joint Attention Condition, as shown by a greater visual preference for a different object—one that was not familiar from the previous interaction with the adult. Deeper object encoding in infants 9 months and younger is also suggested by research measuring event-related potentials in the brain. Greater negative central components were detected when an adult alternated her gaze between infant and object than when the adult produced non-triadic gaze shifts (Striano et al., 2006; Parise et al., 2008).

In a large-scale longitudinal study following infants from 5 to 9 months, Striano and Bertin (2004) found that many infants between 5 and 7 months of age showed joint attentional looks to their interaction partners. These looks increased over time and, by 9 months of age, were often accompanied by smiles. The findings point to an earlier and more gradual development of triadic joint attention than has been proposed by the SIT (see also Striano et al., 2009). Further evidence that a budding capacity for joint attention is underway prior to the end of the first year of life comes from a recent longitudinal study with infants from 6 to 10 months (Salter and Carpenter, 2021). The authors set up a test situation in which interesting sights (or sounds) went on and off in bursts behind an experimenter's back but in front of the infant. In this scenario, infants as young as 6 months made active attempts to engage the adult in joint attention, as shown by sharing looks and smiles. The behaviors increased with age, but increases were not significant for any consecutive months, suggesting a continuous growth of joint attention throughout the second half of the first year.

Adamson and Bakeman tracked how dyadic interchanges gradually develop into increasingly demanding stages of joint attention (Adamson and Bakeman, 1982, 1984; Bakeman and Adamson, 1984; Adamson and McArthur, 1995). According to their "forward analysis," infants in the second year of life get involved in triadic relations first by responding to others' invitations for joint attentional engagement (so-called "passive" or "supported joint engagement") and then by taking on the role of the instigator by showing, holding up, and pointing to objects ("coordinated joint engagement"). Finally, infants deploy symbolic means of reference to create joint attention ("symbol-infused joint engagement"). While their research suggests a progression from RJA to IJA in Mundy's terms (Morales et al., 2000; Mundy and Newell, 2007), Salter and Carpenter's (2021) findings suggest that infants well under age 1 can initiate joint attention if salient environmental changes entice the infant to share her perceptual experience.

Continuity in the development of triadic relations is also suggested by developmental research on imitation and social referencing. Barr and colleagues traced the development of imitation in the first and second year of life (Barr et al., 1996; Barr and Hayne, 1999). They observed that infants between 6 and 9 months are able to reproduce simple actions they observed in others, such as pulling off a puppet's mitten. If given more opportunities than older infants to watch others' demonstrations, some infants between 6 and 9 months imitated even after a 24-h delay (deferred imitation)—a landmark classically thought to be reached in the second half of the second year. This work points to the presence of at least nascent imitative capacities prior to 9 months of age, with continuous growth of this capacity over time. Research on social referencing also suggests a steady growth rather than a sharp onset of object-oriented joint attention. Walden and Ogan (1988) studied the reactions of infants between 6 and 22 months after their parent made emotionally positive or negative remarks about an ambivalent toy. Infants 10 months and older looked to their parent and aligned their subsequent behavior vis-à-vis the object with their parent's message. Infants between 6 and 9 months showed at least some sensitivity to their parent's expressions by looking toward the parent. Although the study might not satisfy strict criteria for social referencing, according to which infants actively seek information when uncertain (Campos, 1983), it shows that infants are responsive to how others interpret novel situations.

This survey of developmental investigations into joint attention, imitation, and social referencing favors the PIT's view of an earlier and more gradual emergence of triadic relations in infancy. It also corroborates the PIT's stronger emphasis on the affective dimension pervading intersubjective exchanges, dyadic and triadic alike, which has been somewhat neglected by the SIT. The considerations we offer not only support the idea of continuity between dyadic and triadic relations but also appreciate the role of affectivity. Hobson and Hobson (2011) finds the debate of joint attention to be too narrowly focused on the "flash light concept" of attention, which abstracts from the various conative and affective dimensions of our orientations to the world. Infants do not imitate adults' visual fixations of objects but adopt affect-laden attitudes by expressing, like their model, e.g., disgust toward the "yucky" food, disapproval of someone's actions, or amusement by a funny object. Infants' smiles in joint attention (Striano and Bertin, 2004; Salter and Carpenter, 2021) and their responsiveness to the emotional tones in social referencing further support Hobson's idea that infants adopt others' orientations *en paquet*, including their affective qualities (Hobson, 2004; Hobson and Hobson, 2007, 2011). We agree with Adamson and McArthur (1995) who stress that rather than becoming lost in transition from dyadic to triadic exchanges, affective tones become more differentiated and are shared with greater explicitness as infants expand their capacities for joint engagement.

If infants' personal connectedness with their caregivers shapes how they approach objects and situations, as indeed the research suggests, then it would be worthwhile to explore the possibility that the attachment bond—which is forged around the same time as infants begin to bring their intersubjectivity to bear on their engagement with objects—modulates the transition from dyadic to triadic interactions. In contrast to non-human animals, human infants express their attachment not just through proximity-seeking behaviors but through communication (Lyons-Ruth, 2007). Perhaps then infants with suboptimal attachment styles are less inclined to share attention with others. In fact, it has been shown that insecurely attached infants involve others less in joint attention than securely attached infants (Schölmerich et al., 1997; Meins et al., 2011; see also Mohammadzade Naghashan et al., 2021), and that maladaptive strategies classified as disorganized attachment are associated with the lowest levels of joint attention (Claussen et al., 2002).

To conclude, both theoretical and empirical considerations of early social-cognitive and social-emotional development support the PIT's claim of continuity in the development from dyadic to triadic intersubjective exchanges and of the PIT's emphasis of the role of affect in the transactions between infants and adults, whether these transactions are dyadic or triadic.

2.5. Summary

In this article, we have contrasted two theses about the ontogenetic beginning of human-specific forms of relatedness and social understanding. One thesis, the PIT, emphasizes the crucial importance of young infants' participation in face-to-face exchanges of affect (primary intersubjectivity), which it regards as the point of origin from which infants' social-emotional and social-cognitive understanding gradually becomes richer and more complex going forward. The other thesis, the SIT, pays relatively little attention to young infants in primary intersubjectivity. Instead, it sees intersubjective relatedness and social cognition as rapidly emerging between 9 and 12 months, when infants begin to share experiences in joint attention. We teased out these accounts' weaknesses and strengths. We agreed with the PIT's criticism of the SIT's relative lack of recognition of young infants' relational capacity and motivation. After all, the same basic communicative competence that infants already display in primary intersubjectivity is "what puts the sharing into joint attention"; and without this sharing, joint attention would not be what it is, as the SIT stresses. We argued that the PIT, by turning the infant in primary intersubjectivity into an object of another's attention, questions the I-You character of the interaction between infant and adult. But we endorsed the PIT's motivation to bridge primary intersubjectivity and joint attention by sketching how one expands into the other in a continuous process, until full-blown forms of joint attention appear around the infant's first birthday. We cited older and more recent empirical research on the development of joint attention, imitation, and social referencing suggesting a more continuous emergence of triadic relations than would be expected by the SIT. In this context, we pointed out that work by Adamson and Bakeman (Adamson and Bakeman, 1982; Bakeman and Adamson, 1984) and Hobson (2004, 2007) adequately captures not only the continuous process with which person-person relations unfold into triadic engagements but also the continued presence and further differentiation of shared affect as infants transition from mutual attention to forming with others a "we" with shared topics of interest and collective pursuits. Future research should be geared to explore this transitional period further, ideally by creating conditions that entice infants to express their desire for sharing experiences.

AUTHOR CONTRIBUTIONS

HM laid out the structure and overall argument of the article. She wrote most of the manuscript. EP, QN, and AL were equally responsible for help with specific parts of the manuscript. All authors contributed to the article and approved the submitted version.

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Pre-verbal Children's Participation in a New Key. How Intersubjectivity Can Contribute to Understanding and Implementation of Child Rights in Early Childhood

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Children's participation and involvement has increasingly been on the agenda for the last few decades. The right for children to participate was established in the United Nations Convention on the Rights of the Child (UNCRC). However, even though the UNCRC gives the right to participate to all children, national policy and practice seems to draw a line on verbal language and exclude pre-verbal infants from participation. The spur of this paper is to challenge the exclusion of infants, to describe how pre-linguistic children communicate their intentions, and to show how an understanding of children's participation grounded in intersubjectivity, can inform and reframe the participation of all children as being fundamentally about close relationships with sensitive and containing adults who look within themselves for the voice of the child. The infant's proto-conversational narrative communicates interests and feelings through sympathetic rhythms of what infant researchers have named "communicative musicality," and it can surface in the mother's narrative about the child and their relationship. Intersubjectivity oppose the monadic view of man as separate and left only to imitate others and claims that humans from the very start are intertwined in a fundamental thirdness of co-created reality. Infants are powerful communicators who actively engage in intersubjective relationships with their caretakers only days after birth, and newborns actively influence and even control the mental process of those who communicate with them. Early childhood participation then, would be to find within ourselves the voice of the child. A research project building on the theories and ideas described in the first part of the article, is presented.

Keywords: intersubjectivity, narrative, infant communication, infant participation, embodied meaning-making, psychoanalytic developmental theory, depth hermeneutic understanding

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INTRODUCTION

> Intersubjectivity is not exclusively confined to a declarative, metarepresentational third-person perspective. We are not alienated from the actions, emotions, and sensations of others because we own those same actions, emotions, and sensations (Ammaniti and Gallese, 2014, p. 9).

Children's participation and involvement has increasingly been on the agenda for the last few decades. Children's rights to participate are founded in the United Nations Convention on the

Rights of the Child (CRC). However, even though the CRC gives the right to participate to all children, national policy and practice seems to draw a line on verbal language and exclude pre-verbal children from participation. In 2005 the CRC Committee made a thorough study of the ways in which infants and small children should be able to participate, and they strongly stated that infants have the rights to participate and be heard. The Committee on the rights of the child (2005) recommended to give the highest priority to the study and development of specific methods for infant participation. By "infant participation" we mean: having an influence on infants life-world, and on decisions that have bearing on infants both as individuals and as a (vulnerable) group in society. We think that infant participation should be an ongoing process and elaborate on this below.

Lyons-Ruth et al. (2017) describes the worldwide burden of infant mental health and paints a picture of utmost urgency for the world to take better care of infants and their human rights. Colwyn Trevarthen, leading infant researcher for over five decades, makes this warning explicit in his editorial for the European early childhood education research journal: "Any human community, large or small, primitive or civilized, that neglects to provide care and companionship to its infants and toddlers, responding to their affections, imagination and "zest" for both well-being and learning, will have cumulating problems with its health and behavior, and with its economy, too. Training intelligence and ability to work for an income is not enough. Even the youngest human beings have to be respected and accepted as whole reasonable persons, with all their impulses, feelings and habits, and preferred companions, as Comenius advised in the seventeenth century." (Trevarthen, 2012, p. 310).

In the field of children's participation, there is a promising tendency to include infants and to start to understand and figure out how even the youngest children should be included in the participation and citizenship paradigm (Ulvik, 2015; Horgan et al., 2017). In a recent publication, Hultgren and Johansson (2018), writing from a Swedish context, address the inherent rationalistic or positivistic view of participation "as an activity carried out by competent, responsible, reflexive individuals, that is, adult-like individuals." (p. 2). Hultgren and Johansson challenge the views of "participation as something that concerns decision-making and that children's participation is an issue of the degree to which they can share in decision-making." (p. 1–2). The authors propose and describe a new model of participation based not on decision-making and verbal language, "but as an ongoing process" (p. 2) also including infants and pre-verbal children. This is a very good start, and the authors describe a nicely created program in a children's library where young children participate and contribute to the agenda. The library staff actively set up a hermeneutical circle of reflection helping them to challenge their preconceptions of children's participation and to be more sensitive and curious in their contact with the children. However, this study has one main deficiency: the fundamental relational and intersubjective basis of the human condition is not included. In a very recent publication, von Bonsdorff (2021) voices a similar critique of the modern discourse on infants and human rights. This deficiency, which we agree is typical for the recent literature on infant participation, is our point of departure in this article.

This article is an attempt to contribute from psychology, developmental and psychoanalytic, to the understanding of even small children's right to participate and partake in common cultural exchange and meaning making. The understanding of participation should expand from a narrow legal and rationalistic endeavor, to a primarily relational and intersubjective process. As von Bonsdorff (2021) suggests, "we need a more holistic approach, which does justice to infants' playful, interactive and affectionate initiatives." (p. 37). We hope that our contribution can be to demonstrate how infant intersubjectivity can have a significant influence on understanding and practice of infant participation.

This article is twofold. Firstly we try to describe a theoretical foundation for infant participation. Secondly we describe a research project building on this theoretical foundation and having the goal of introducing a practical way of helping infants to participate concretely. We have the ambition that this article can contribute to an increased interest on how infants can have their rights to participate realized, in practices such as infant mental health, midwifery, child protection and public health services. But we also hope that our somewhat rhetoric art of stating explicitly the rights and possibilities of infant participation, can bring the needs of infants and small children higher up on the agenda of politics and decision making in society.

The authors field of work and research is infant mental health, child protection and public health. The first author is associate professor with a Ph.D. in clinical psychology and psychoanalysis, and is a clinical child psychologist and child psychoanalyst working with infants and their parents. The second author is a Ph.D. student, family therapist and clinical child and family consultant working with infants and parents in the context of midwifery and public health services.

Our epistemological point of departure is in line with modern psychoanalytic and psycho-social research emphasizing the subjectivity of the researcher, the continuous back and forth influence between research material and researcher, the relational or mutual creation of meaning and the importance of reflection on one's own listening position (Reeder, 2002; Rustin, 2012, 2019; Hollway, 2015; Hamburger, 2017; Cummins and Williams, 2018; Salling Olesen and Leithäuser, 2018; Holmes, 2019). We try to do our research in line with psychoanalytic participant observation (Rustin, 2012, 2019) and mostly in opposition to a rationalistic, removed and (clinically) neutral registration and recording of behavior. In this context, our knowledge mainly comes from interaction and interpreting interaction.

Infants Communicate Their Intentions–How Can Grownups Listen?

We want to describe how pre-linguistic children communicate their intentions, and to show how an understanding of children's participation grounded in intersubjectivity, can inform and reframe the participation of all children as being fundamentally about close relationships with sensitive and containing adults

who look within themselves for the voice of the child. We also want to give a preliminary description of a research project that could bring us closer to a specific method of understanding and tapping into the voice of pre-verbal children and thereby helping us to fulfill the human rights of even the youngest citizens.

Our argument rests upon an understanding of the human condition as basically two-person or intersubjective and therefore a main section of the article is devoted to a description of intersubjectivity and how this can help us to understand and develop a new model of infant participation.

Infant participation could not be about decision-making. We cannot ask a 6-month-old if she/he wants to live with mum or dad after a divorce. But we can be certain that the infant will be affected by the relationship breakup. Through interacting with the infant (or the infant together with his/her parents) and then producing a narrative about this interaction and the child, we can try to find the voice of the infant in our own words. The child will not reveal to us where he/she wants to live (mum or dad), but the infant will probably convey to us that he/she dislikes the present situation and his/her family being in ruins. The participation comes into action not as some sort of hybrid decision-making, but as an ongoing intersubjective process making grownups more sensitive to the child's intentions and conscious of the infant's perspective. This kind of broadened understanding of the situation can make the parents take into consideration that their infant also has something to say and that he/she will be affected by their decisions to a great extent. This is infant participation–that grownups learn to understand infants as communicative, that they must act as a companion in communication, and that they can find inside themselves the voice of the child. Grownups should get to understand that infants are not indifferent, but highly intentional and meaning making creatures, wanting to have their opinion heard and legitimized.

The discourse around children's rights and participation, has usually been about what can be done or how can authorities intervene on behalf of children. But what really counts in child development and quality of life, is the relationship to primary caregivers. The primary relationship should be regarded as the most important arena for participation, influence and co-created meaning. We should not forget the continuous embodied interdependence of infancy. Infants use their whole body to communicate their intentions, what is called an "enkinaesthetic polyphony" (Stuart and Thibault, 2015). We cannot understand infants by investigating them from the outside using a rational view looking for static contents of their minds. We have to participate with the infant, engage in conversation and open up for the impact the infant can have on us. If we can create a culture where infants have the opportunity to engage us and we decide to meet them with openness, recognition and admiration, the number of co-constructing communicative events filled with meaning, will increase significantly.

Perhaps we should try to turn it all around, stating that participation is not so much about increasing the way children partake, but about grownups being much more involved with small children and infants, taking great care in the narratives we produce about the participation.

An Intersubjectively Created Narrative

These three human beings, put here on display (**Figure 1**), try in different ways to execute their rights as fellow citizens and members of society–we could use this as an example of citizenship and participation, at least a situation that gives us an opportunity to consider the rights of small children to participate and be heard.

FIGURE 1 | Reuben Saidman (1906–1967)/National Media Museum. Republished with permission from the National Media Museum.

Nobody likes to be put on display, infants are no exception. These three young fellows try in different ways to tell us their opinion about being part of a "cattle show."

The one to the left, gently patting his fellow citizen on the back and through identification with the distress of his neighbor shows the world with an annoyed look that this is not all right.

The person in the middle has reached the point of no return and is really pissed-off. There should be no doubt anymore–this member of society opposes the whole idea of being displayed and wants to go home with her mum. But mum is only laughing and there is no hope anymore of having her human rights accepted and respected.

The last child tries to help the crying baby to get rid of a troublesome stick or brush, and as you can see, supported significantly by her mum from behind, would like to throw the brush against the audience to move the center of attention elsewhere and to state clearly that the show has to end.

This kind of spontaneously formulated narrative is of course heavily colored by the creator's (first author) own subjectivity (one major part of this subjectivity is the ability and willingness to make the narrative). However, we think that this kind of narrative includes a core, containing some intersubjectively created meaning about the infants' situation. These infants can have an impact on us provoking a narrative embodying their voices. The impact would of course be much more intense if we were present and had been interacting directly with the children, and would be even stronger if we had a caring function for one of them.

INTERSUBJECTIVITY

Like adults, infants behave as if they care about what's going on in their world. Their close and caring relationships would be impossible without the intersubjectivity manifested by their prolific but directed emotional expressions. Infants are extremely engaging and intensely focused on making an impact. In the words of Colwyn Trevarthen (1979): "In any attempt to understand infants as communicators it must be noted that the effect of the emotional expression can only be interpersonal. Only another person capable of emotion can be influenced by an emotional sign." (p. 323).

We will not go into detail on the huge amount of research that supports infant intersubjectivity but limit ourselves to a description of the phenomena and understanding of its implications. Research on infant intersubjectivity has been described in detail by (cf.) Trevarthen and Aitken (2001), Bråten and Trevarthen (2007), Zlatev et al. (2008), Bråten (2009), and Ammaniti and Gallese (2014).

It is tempting to use the seminal book *Before speech* edited by Bullowa (1979) as our starting point in grasping how intersubjectivity in developmental psychology can make a ground-breaking contribution to infant participation and citizenship. One of the very first, and widely cited, contributions by Colwyn Trevarthen, is part of this book. We have already quoted him above. Trevarthen's chapter is called: *Communication and cooperation in early infancy: a description of primary intersubjectivity* and pointed toward the next four decades of research into the communicative abilities of even the youngest children.

Trevarthen (1979, 1993, 2001, 2011, 2015, 2016) has been one of the most influential and inventive researchers of infant development. His description of primary intersubjectivity has been a cornerstone of intersubjectivity theory and contemporary understanding of infant communication. Research on engagements between infants and parents proves that human beings are born with subjectivity and a drive for intersubjectivity. Trevarthen proposes that the infant is born with a receptive competence to grasp subjective states in other persons and to engage in conversation based on this competence.

The Norwegian expert on infant intersubjectivity, Stein Bråten, speaks of *altercentric-participation* (as opposed to egocentric). This is "the manifestation of an intersubjective capacity for participant perception, entailing that the perceiver resonates with what the other is doing or trying to do or say, as if the perceiver's frame of reference were bodily centered in the other." (Bråten, 2007, p. 117). Bråten and Trevarthen has been in close collaboration through the years, and together with others (cf. Beebe and Lachmann, 1988; Tronick, 1989; Kugiumutzakis, 1998; Meltzoff and Moore, 1998; Jaffe et al., 2001; Stern, 2004; Reddy, 2008; Beebe et al., 2010; Beebe, 2014) they have given us a widely recognized understanding of intersubjectivity and infant communication. Now is the time to use this knowledge in the interest of one of the most vulnerable groups in society, and to give them an increased opportunity to participate and have influence on their own condition (in accordance with the policy of the UNCRC).

The research referred to here has illustrated again and again that infant communication should not be regarded as more primitive and only a simple shadow of adult conversation because infants lack verbal language. Infants can express their wishes, needs and intentions in much the same way as we find among youngsters and even adults (Murray and Trevarthen, 1985; Bråten, 1998; Kugiumutzakis, 1998). In the words of Trevarthen and Aitken (2001, p. 6), summing up the research on infant intersubjectivity and communication: "Importantly, the behaviors selected to define the infant's intersubjectivity–the ways the infant look, express their feelings in face and voice, how they gesture and move in rhythmic cycles to accept or reject contact–were homologous with behaviors that are essential to the elaborate intersubjectivity of all collaborative intentional activity in adult society, including live conversational language."

Infants Are Response-Able

The late Norwegian professor of psycholinguistics, Rommetveit (1998), said in response to the rationalistic and positivistic view of children's participation and moral development: "The infant is . . .*response-able*, i.e., able to respond, but not (morally) *responsible* for its contributions to the interaction." (p. 364; italics and underline in original). The spontaneous, not reflectively monitored, transcendence of the infant's immature self into the feelings and intentions–and narratives–of the adult caretaker, is a pre-requisite not only for entrance into a community of meaning, but also for the development of moral agency.

Returning to the picture (**Figure 1**) of the display: One of the students of Colwyn Trevarthen, Bradley (2009), questioned the validity of information taken only from mothers or other adults with their infants, and went on to demonstrate the rich adaptations for communication, exploration of relationships and artful invention among infant peers from before 6 months of age. They (the infants) said: we are born "sociable," not just for mothering. Infants communicate, they are interested in what's going on in others, they have an impact on every sensitive human being, they are able to contribute and to respond. The company of an infant will be charged with intersubjectively created meaning. And if grownups take the task of putting into words what this interaction with the infant has done to them, the meaning can emerge and create a new potential for action and intention. This type of narrative can have an immense potential, as Trevarthen and Delafield-Butt (2013, p. 190) states: "In a narrative, separate psychological events or actions become one evolving experience, a product of an integrative action of the brain and body joining separate moments of conscious commitment and emotional evaluation in sequence to make a single and new project. That is the job of a narrative."

Intersubjectively Created Narratives

As Trevarthen and Delafield-Butt declare in the quote above: narratives are how we make our self-conscious agency meaningful to others, and this goes also for infants. The narrative influenced by the picture of the three young citizens, is an example of intersubjective communication. The narrative is a co-created story containing ingredients from the infant's narratives as well. Delafield-Butt and Trevarthen (2015) states: "Narratives do not have to be linguistic. Understanding the pre-verbal origins of narrative is fundamental for understanding human cognition and culture" (p. 9). They also site Bruner (1990, p. 77): "Narrative structure is even inherent in the praxis of social interaction before it achieves linguistic expression." The three children in the picture should absolutely be regarded as storytellers in the first degree. Their story ingrains my (first author) story.

Mental life, from cradle to grave, is an ongoing process of narration (Bruner, 1990). Our whole life is a continuous story-telling. We contribute heavily to our own life-story, except at the beginning and at the end. At the start and closure of life we are in the narrative mercy of someone else. There is a narrative already in place before we can start to develop our own, and this (pre-) narrative will influence significantly on our own agency and ability to continue the production of our story (MacIntyre, 1981; Ricoeur, 1992). When we enter the world, we are thrown (to use a term from Heidegger) into a world (or a narrative) where a community of persons already have started to tell the narrative of our life. Life narratives are produced in story-telling contexts. The story-telling context can produce a narrative that gives room for the infant's own agency, or it can restrict the young child's own influence. In the research project (described below), we will analyze the story-telling context of parents and professionals in conversation about the (coming) child, and try to find the child's agency in the narratives produced there.

Another primary contributor to the famous book edited by Margaret Bullowa, was Bateson (1979). Her delicate observations and understandings of one mother-infant proto-conversation, illustrated that both mother and infant "were acting to sustain [the conversation] or to restore it when it faltered." (p. 65). This mutual effort and responsibility to create and maintain the communication, reveals what Trevarthen and Delafield-Butt (2013) names "a fundamental *motive force* for intersubjective connection, for sharing what is in mind, and for making sense of existence in a human-made world." (p. 191; italics in original).

The newborn expects the responsive company of others and this is even present before birth (Piontelli, 1992; Meltzoff and Prinz, 2002). Striking evidence of a readiness for communicating with others comes from detailed observations of close encounters with infants just hours old (Meltzoff and Moore, 1998; Trevarthen, 2011). In one illustrating example, a newborn was observed in dialogue with her father 4 weeks after her premature birth at 27 weeks' gestation (Trevarthen, 1999). This case clearly demonstrates the inborn expectancy for human company and communication (Trevarthen and Delafield-Butt, 2013). Infants insist on communicating and wish for conversation with other human beings from the start of life.

Trevarthen and Aitken (2001) describes what they call a "shared narrative awareness" where the infant can also be the leading part. Together with a parent or another familiar person, the infant "can take the role of instructor or informer to the adult's communications [. . .] The infant gives an external curriculum of motive changes for the parents' intuitions to follow, and this curriculum changes intrinsically as the infant develops. It is not simply a reflection of what the infant has been taught." (p. 16). Infants are not compliant imitators of familiar adults who engage with them in joyful celebration, they are active and stimulating performers often making the initiative and leading the other (Schögler and Trevarthen, 2007).

When we are seeking a narrative understanding of the other's feelings and intentions, we are not just characterizing the other's inner life in the form of causally working mental states. What we try to understand is much more prolific and comprehensive. We try to grasp the other's (infant or adult) reasons and causes as they reveal themselves against the whole history and myriads of potentials. The narrative form is the best way to capture this rich and complex communication. When we try to understand another's reasons, we are not revealing their discrete mental states, but their perspectives and responses as whole situated persons. To produce a narrative about an infant would not primarily be to create a description of what is "going on inside the infant's head." Instead, the narrative would tell a meaningful story about what is going on in the world surrounding the infant, and this is a shared world, we are also living in the same world and in the child's life from moment to moment. This is why the narrative comes to us as a primary example of intersubjectivity, because it contains a direct form of understanding of the other's life and responses. The adult narrative will be ingrained (and even dictated) by the child's performance. Attending to a narrative framework activates our subpersonal mechanisms for imitative and emotional responding, because it embodies our engagement and creative, say life-giving, potentials (Currie, 2007). This type of

understanding intersubjectivity can be given the name "second-person approach" (Ammaniti and Gallese, 2014). It tangents neuroscience and the discovery of the mirror neuron. Vittorio Gallese had a central role in the research on mirror neurons and in several articles (Gallese, 2001, 2005) he proposes that our capacity to share experiences with others comes from the formation of a shared meaningful interpersonal space. Gallese names this shared capacity a "shared manifold," a primitive, but, nevertheless, significant and fundamental we-centric space.

The grownup's narrative about a shared life-world with an infant, should then not be understood as a "story about what's inside the infant," or what's inside the grownup's reverie or fantasy. We should take the narrative as a primary way of the child to put his/her reasons and intentions into adult language. We could say that the grownup speaks on behalf of the child, but without doing this consciously, more like a "medium" without the magic, this is serious business. Intersubjectivity holds that it is not possible, or even preferable, to sort out what's mine and what's yours, but that it is co-created, more like a third (Ogden, 1994; Benjamin, 2018) entity or fact. From this we can postulate that the voice of the child rests in the voice of the adult. This can obviously come to a cartesian mind as a challenging mental ordeal. But it is very gratifying and significant in the day-to-day practical work with infants and their parents. And for the majority of parents caring for their newborn, this is no surprise.

An understanding of the rights of the child to participate grounded in intersubjectivity and intersubjectively created narratives, makes the way for including infants and toddlers, and bringing them closer to the table when society decides about their needs and wellbeing. If we as grownups could act more like "*companions in meaning making*" (Trevarthen and Aitken, 2001), the rich and comprehensive messages from our youngest citizens, could guide us in developing the "culture of a cooperative society." (Delafield-Butt and Trevarthen, 2015).

A PSYCHOANALYTIC CONTRIBUTION

We start this section about the psychoanalytic contribution by presenting another illustrative example: let us enter the Greek myth of Oedipus where the shepherd Phorbas rescues the infant boy and thereby makes Oedipus able to fulfill his destiny. Hearing about an infant, mutilated by his own parents and left in the forest to die, surely has an impact on all of us. This is probably one of the main reasons why the myth has survived, and through psychoanalysis, has become part of folk psychology.

The Norwegian word for participation or user-involvement is "*medvirkning*." The word has two parts "*med*" and "*virkning*." The first part translates into "*with*" and the last part "*virkning*" means literally "*impact*." So, the word "*medvirkning*" equals "*with (an) impact*." Impact is the key word here. We need to understand the impact, or the sharing and intersubjective, dual, non-monadic way we as adults understand infants through the influence and effect they have upon us. They emotionally affect us. We do not need a theory-of-mind, we already have an innate ability to grasp what the infant conveys through our sensitivity and understanding as part of a common culture and community, as the Oedipus myth confirms. Psychoanalysis has understood this human existential constant and has made good use of it through the concepts of countertransference (Money-Kyrle, 1956; Brenman Pick, 1985/1997) and projective identification (Bion, 1962).

Safier (2000) talks about the "impact of having the baby in the room." The impact is not always a pleasant one. The British psychoanalyst and pediatrician Winnicott (1958) wrote in his illuminating paper "Hate in the countertransference," how "the mother hates her baby from the word go." (p. 201). Winnicott explained how a mother deals with this: "The most remarkable thing about a mother is her ability to be hurt so much by her baby and to hate so much without paying the child out, and her ability to wait for rewards that may or may not come at a later day." (p. 202).

Very often, the impact, communication and understanding happens unconsciously. Even if the situation is obvious and the intersubjective communication is straightforward, the adult does not immediately understand. This is an inevitable part of everyday life. Different degrees of sensitivity due to psychic state, personality, other demands, contextual support, postpartum depression, etc. will of course influence on the parent's ability to deal with the impact of the intersubjective communication (Gratier et al., 2015). In research and clinical work one should of course try to give caregivers an open and attentive ear, and take into consideration their potential difficulties. If we want to understand the life-world of an infant trying to communicate, trying to have an impact, we have to be open and sensitive to the everyday ordinary struggles of parents and infants. And we should do what we can to support caregivers in their strive to understand what their infant tries to convey. Psychoanalysis makes an important contribution to our understanding of infant intersubjectivity, not the least through highlighting the conflictual dynamics and the unconscious functioning of the relationship between parents and children that is often undervalued in infant research.

Psychoanalytic Developmental Theory

In his book, *The Present Moment in Psychotherapy and Everyday Life*, psychoanalyst and infant researcher Stern (2004, p. 81) says: "The essential point is that when people move synchronously or in temporal coordination, they are participating in an aspect of the other's experience. They are partially living from the other's center." Modell (1993, p. 120) making an obvious connection between intersubjective infant research and modern psychoanalysis, states that: "mother and infant unconsciously replicate within themselves the affective experience of the other." Modern psychoanalysis, often named the "relational turn," suggests that subjectivity is interpersonal from the beginning and reject the intrapsychic conception of the mind sustained by psychoanalysis for almost a century.

Lyons-Ruth (1999), representing relational psychoanalysis, states that "Recent psychoanalytic theory has moved increasingly toward a relational, intersubjective and social-constructivist stance" (p. 576), and she introduces the concept "two-person unconscious" as an alternative to the Freudian intrapsychic "dynamic unconscious." The two-person unconscious includes

implicit or procedural forms of knowing. "Procedural forms of knowing are not only infantile, but are intrinsic to human cognition at all ages and underlie many forms of skilled action, including intimate social interaction" (ibid, p. 579). Procedural forms of knowing includes the understanding of infant communication. "The re-transcription or translation of implicit relational knowing into symbolic knowing (for instance verbal language), is laborious, is never completely accomplished and is not how developmental change in implicit or procedural relational knowing is generally accomplished" (ibid, p. 579). The process of creating adequate intersubjective recognition in development requires close attention to the infant's initiatives in interaction, because through these initiatives, the child communicates his or her goals, motives, intentions and their meaning structures. Without recognition of one person's (the infant) initiative communications by another (the parent), no intersubjectivity or dyadic regulation is possible. Therefore, Lyons-Ruth as a practicing psychoanalyst knows very well the "active negotiation and repairing of miscues, misunderstandings and conflict of interest" (ibid, p. 584), that are inherent in every psychoanalytic relationship between patient and analyst, and in every parent-infant dyad.

"The concept of projective identification is an important bridge between psychoanalysis and the intersubjective approach." (Ammaniti and Gallese, 2014, p. 35). Through projection of thoughts, beliefs and parts of the self together with the change that takes place in the person receiving the projection, the first person is, one could say, actualized in the latter, and usually without any awareness of what is going on before the receiver discovers it in his or her own behavior, thinking or narrative. This is extremely relevant in the parent-infant relationship. Ordinary devoted parents attributes heavily into the child (Seligman, 1999). In addition, the other way around, the infant is extremely dependent on the use of projective identification as a primary way of communicating his or her intolerable state to the parent, and to receive back a digested version made comprehensible by the parent's reverie and containing abilities (Shuttleworth, 1989). Infant and child development rests upon the relational dynamics of the child's ability to communicate its mental state, and the impact it makes on the caregiver. "Understanding would then be synonymous with receptivity, reverie and alpha-function," (Norman, 2001, p. 94).

We should also highlight the contribution of psychoanalytic infant observation (Rustin, 1989, 2012, 2019; Urwin and Sternberg, 2012) to our knowledge of infant communication and development. Through an enormous number of naturalistic observations of infants and toddlers across their first years of life, psychoanalytic infant observation has given small children a strong voice and made us understand how they participate and have an impact on us. Building on the classic contributions of Bick (1964, 1968), psychoanalytic infant observation maintains that "emotions, qua emotions, have to be *felt* in some way, even if in a very mild identificatory way, to be faithfully recorded by an observer. It is precisely this element of intersubjective communication (more controversially, 'unconscious to unconscious communication') that is reflected in the first-person account, with its use of 'subjective' and evocative language where 'every word is loaded with a penumbra of implication' (Bick, 1964)." (Price and Cooper, 2012, p. 57, italics in original). To ask parents to produce a narrative about their infant should therefore be a self-evident way of finding the voice of the infant (as we will elaborate on below).

Another major point made by psychoanalysis and psychoanalytic infant observation, is the same as Van Manen (1990) declares of every form of phenomenological inquiry: "we know too much." We come to the encounter with an infant with too much pre-understanding, common sense, scientific knowledge and the like, and we can become unable to grasp the intersubjectively created question: "what is this new member of humanity trying to tell us?" We need what psychoanalysts call "negative capability" (Bion, 1970), a concept Bion borrowed from the poet John Keats. It comes to us as a capability "of being in uncertainties, mysteries, doubts, without any irritable reaching after fact and reason." (p. 125). And we should add the wise words of Symington and Symington (1996, p. 169) when they say that "Negative Capability is not an immediate mental discipline to be engaged in just prior to the session, but rather a way of life." This is the way of life that psychoanalytic infant observation and infant intersubjectivity can teach us, and it is the way of life that can give our youngest citizens a stronger voice through our lenient openness for what they really have to say. Through our negative capability we can continue to be susceptible and open to the fact that every word in our narratives about infants is loaded with a penumbra of implication, as Esther Bick told us.

A METHOD FOR TAPPING THE VOICE OF THE INFANT

In the tradition of psychoanalytic infant psychotherapy (Norman, 2001, 2004; Paul and Thomson-Salo, 2014; Safier, 2000; Salomonsson, 2014), "[t]he central therapeutic mechanism is thought to lie in trying to understand the infant's experience from the infant's point of view and conveying to parents and the infant that the infant has a mind of their own, with their own understanding of their experience." (Paul and Thomson-Salo, 2014, p. 8). And we could add: trying to convey that the infant participates and want to be heard and to have an impact. The method is already there, developed from psychoanalytic infant observation and psychotherapy, and intersubjectivity gives us the theoretical, scientific and philosophical foundation to start tapping for the infant's opinion. In this section, we will describe a research project designed to find the infant voice in narratives made by parents. The research is part of the second authors Ph.D. project at Inland Norway University of Applied Sciences and is done in cooperation with the public health services and midwifery section of Kristiansund municipality on the west coast of Norway. The project set off in early spring of 2021. The first author is supervising the project and takes part in the interpretation and understanding of the data material.

Research Project: How Parents and Professionals Can Become "Companions in Meaning Making"

Trevarthen and Aitken (2001) in their scholarly paper on infant intersubjectivity, describes how a parent can become a *companion in meaning making* through primary (and later secondary) intersubjectivity. This companionship is a real and very effective form of informed action and engaged empathy, and our research project, has as its main goal to find and illustrate this very powerful way of intersubjectivity and infant participation.

The research project involves three distinctive stages. First, as part of a semi-structured interview with a professional (health visitor, midwife) before, and again around 6 months after birth, parents is encouraged to make a narrative about their child. The narrative can be oral or written. Both interviews will be videotaped and the audio will be transcribed. Between 15 and 20 parents will be included in the project, primarily mothers, but also the fathers narrative is of interest to us. Second, the parental narrative is interpreted according to a depth-hermeneutic method (Bereswill et al., 2010), called "scenic-narrative microanalysis (SNMA)" (Hamburger, 2017), based on the theories of scenic understanding first developed by the German psychoanalyst and sociologist Lorenzer (1970, 1986). Third, videotaped interplay between infant and parent at around 6 months after birth, is analyzed using the parental embodied mentalizing (PEM) instrument (see below).

Temporally coordinated expression (coordinated rhythm, prosody and interactive dynamics) forms the basis of a spontaneous communicative musicality in the first months of life (Malloch, 1999; Trevarthen, 1999; Gratier and Apter-Danon, 2009). Musically lived-through narratives can inspire and (at least partly) be reproduced after the interaction. The meaning making comes through the passing of intentions and emotions between infant and parent in "proto-narrative envelopes" of vitality (Stern, 2010). When a parent (or professional) who has been engaged in conversation and/or companion with an infant, elaborates in verbal story-making or singing, the grownup person makes sense in their own language, of the intentions and prospects delivered from the child through the proto-narrative envelopes, as "a semiotic experience for consensual understanding" (Delafield-Butt and Trevarthen, 2015, p. 12). In our project, on all three stages, we would especially look for the rhythm, pulse or prosody that makes an impact on us.

The Rationale for Asking Parents to Make a Narrative Both Before and Again After Birth

Martiìnez Quintero and De jaegher (2020) speaks about pregnancy as a type of intersubjective relation between mother and fetus. Both mother and fetus participate in a kind of minimalistic sense-making, trying to figure out how to grow and develop in the new environment, seeking a kind of agency to exist and maneuver, for the sake of a common survival. It's a kind of embodied sense-making, forwarding some interesting questions about fetus consciousness and/or intentionality (Hata et al., 2015). Even though this may be open questions, we follow the line of Delafield-Butt and Gangopadhyay (2013) when they say that the fetus shows an embodied kind of primary intentionality that develops from early in pregnancy. We consider this to be a kind of "not one, not two" but a cooperative system "that emerges as an autonomous relational organization" (Martiìnez Quintero and De Jaegher, 2020, p. 14).

The coming mother's experience of pregnancy and the growing fetus inside her, is of great interest in our project. Do the mother experience herself mainly as a container for the fetus or does she consider the fetus to be a part of her maternal body? (Kingma, 2019). The first may lead to a feeling of alienation, the latter may lead to an experience of cooperation between mother and fetus. We would like to call this cooperation "the birth of intersubjectivity," and it happens before the physical birth. We assume that the mother's experience of intersubjective partnership in sense-making with the fetus, can influence significantly on the quality of narratives about the infant after birth. We presume that the narrative made by the mother-to-be can reveal traces of this dichotomy: container or partnership (of course, in real life it will not be dichotomous, but more like a dynamic continuum). And we presume that the mother's experience of cooperation with the fetus will affect the cooperation of sense-making with her infant after birth.

Scenic-Narrative Microanalysis

"Scenic-narrative microanalysis assumes as a principle that meaning itself, and not only in the field of human psychology, is a relational phenomenon." (Hamburger, 2017, p. 168). The meaning we are looking for is both created (in the parent-infant dyad) and understood (in the research group struggling to find the meaning-making narrative) relationally. SNMA was first developed, as a central part of the Yale video testimony study (Laub and Hamburger, 2017; Hamburger, 2017), to analyze and interpret videotaped interviews of Holocaust survivors. In our research project the data material to be analyzed, comes in the form of audio or videotaped interviews containing parental narratives.

The depth-hermeneutic method of interpretation consist of an intense group process with challenging negotiations to identify scenic or intersubjective moments-of-meeting (Stern, 2004) in the narrative material. The narrative material will be transcribed and made ready for the research group to dive thoroughly into, not only looking for the manifest verbal accounts, but also searching for hidden treasures in the narrative expression. Our presumption is that we can find some traces or even a clear resonance of the infant's voice inside the parents' narrative, and that we can find a qualitative development in the narratives ability to carry the infant's voice from the time of pregnancy to the time of interaction a few months after birth.

Based on Hamburger (2017), the interpretive process of SNMA in our project, takes place on four consecutive steps or levels:

(1) Every single researcher (or member of the research team) expose her/himself to the transcribed raw material including

the parental narrative. The researcher underlines and documents her/his transference reactions to the material.
(2) In one or two meetings of the research group, the reactions or provocations (see below) of each individual member, is discussed and compared. Most important: the group reactions and "moments of heated debate" are also recorded by the main researcher taking the minutes.
(3) In a new meeting of the research group, the minutes from the first meeting is presented and debated, again to identify and negotiate provocations (see below).
(4) The main researcher then makes a conclusive discussion of the material from the group meetings.

In our research project the main outcome produced, and which we assume would contain traces of the infant voice, is the minutes from the research group meetings and the conclusive discussion of the material.

To Identify and Negotiate Provocations–the Backbone of Scenic-Narrative Microanalysis

The narrative approach is especially well suited to study and look for intersubjectively created signs of communication. Parental narratives infect the research group and elaborates in the collective continuous process of negotiation and interpretation. At one point we tap into this ongoing and neverending process to look for the voice of the infant.

According to Lorenzer (1970, 1986), and emphasized by Bereswill et al. (2010), Leithäuser (2013), and Hamburger (2017), the interpretation and understanding of a text should be based on the identification and following of "provocations." The text could be any type of qualitative research material, including interviews and narratives (Bereswill et al., 2010; Hamburger, 2017). The researchers in our project are looking for the surprising, worrying, disturbing, confusing, irritating (and so on), parts of the parental narrative. And in the group meetings of three or four researchers, their respective provocations are discussed and debated. This debate can sometimes become quite heated, and this illuminates and reveals, through the researchers' transferential potential, important intersubjective aspects of the parental narrative. This method is similar to the familiar practice of psychoanalytic infant observation where the main point is to observe and reflect on one's affective (embodied) responses to presented material in the infant observation seminar (Rustin, 1989, 2019; Hollway and Froggett, 2012; Urwin and Sternberg, 2012; Music, 2017). Swedish psychoanalyst and infant researcher, Salomonsson (2014) names this interpretative work "*adultomorphizing*." He states: "I therefore suggest we understand babies via a *qualified adultomorphizing*, namely, by reclining on *analogic representations linked to our own bodily experiences*." (p. 38; italics in original). And he continues: "Once, when they were created in our infancy, they copied our affects' gestures and contents. Today, in front of the baby [or the narrative about the baby], we recognize the similarity between his behavior and our representations." (p. 38). The basic assumption is that the identification, understanding and truth of the provocation, does not only reside in the single receiver. Provocations are collective "in the sense of shared socio-cultural meanings drawing on the necessarily social quality of collective experience embedded in interaction forms." (Hollway, 2015, p. 131). This gives us the foundation to claim that the infant voice can be found in the parental narratives, if we are willing to endure the demanding process of finding and negotiating what provokes us there. Or we could say: The infant has an *impact(a)* on the parent, the parent produces a narrative in a story-telling context together with the midwife or health-worker, and this narrative has an *impact(b)* on the researcher(s). Our presumption is that *impact(a)* and *impact(b)* will be related and this connection makes it possible to find the voice of the infant in the provocations that turns up in the research group meetings.

Parental Embodied Mentalizing

In our upcoming research project, we will also use an instrument developed by Shai et al. (2017), Shai and Meins (2018) called PEM. PEM stands for "Parental Embodied Mentalizing" and is both the name of the instrument and the name of an important developmental and relational phenomena in the early interaction between infants and parents, which the instrument measures. Shai and Belsky (2011, p. 187) states that: "PEM is defined as the 'parental capacity to (a) implicitly conceive, comprehend, and extrapolate the infant's mental states (such as wishes, desires, or preferences) from the infant's whole-body kinesthetic expressions and (b) adjust one's own kinesthetic patterns accordingly"'. The main contribution of PEM, as a clinical and research instrument, is to uncover and operationalize parental reflective function (PRF), but moves beyond parents' verbal and declarative capacities, toward an embodied "enkinaesthetic polyphony" (Stuart and Thibault, 2015). In accordance with the scientific foundation of our research project (as outlined in this article), PEM builds on the notion that "the development of children's sense of ownership and agency at the embodied level necessitates the interpersonal encounter, mediated by PEM." (Shai and Belsky, 2011, p. 187). Co-created narrative engagements between infant and parent, forms intersubjective events rooted in the sensorimotor (and thereby mostly unconscious) domain. PEM can help us trace these intersubjective events in a controlled and standardized way. The PEM analysis is based on the interpretation of a videotaped 10-min play sequence between infant and parent. The second author will do the filming. The play sequence is interpreted according to various embodied categories: pacing, direction of the body, tempo, space, pathway of movements, tension flow, initiative and so on. PEM usually generates an overall rating of parent sensibility. But in our research project, the different categories of embodied interaction highlighted by PEM, will be emphasized. We want to look for clues or traces in the embodied cooperation between parent and infant, that adds something to the depth-hermeneutic analysis (SNMA) of the narratives. Both PEM and the semi-structured conversations between parents and midwife/health visitor, are cooperative sense-making situations, and can therefore contribute and create narrative data suitable for the qualitative search for the voice of the infant.

The PEM classification rests upon the idea that the parent-infant interaction is an ongoing common meaning-making (a non-verbal narrative) and is comparable to the concept of communicative musicality (Malloch, 1999).

In using PEM, the professional or researcher analyses the child-parent interaction from an "outside" position, meaning that the researcher should not take into consideration the emotional (or personal) reaction in his/her own mind. PEM can be seen as a type of "exterior" analysis; looking on the outside to make a judgment. On the opposite, the depth-hermeneutic method; the SNMA, puts the emphasis on the emotional (or personal) response of the researcher and can therefore be regarded as a type of "interior" analysis; looking inside the researcher's mind to make a judgment.

To compare a PEM score with a depth-hermeneutic analysis of parental narratives, can be challenging because they come from quite different epistemologies. Even so, we want to use a combination of the two sorts of empirical data in a mixed methods design, because we think that the exterior and the interior is not necessarily mutually exclusive. They may be "two sides of the same coin," and at least that is what we want to investigate.

In our research project we want to compare the PEM analysis of each individual parent with their narrative. We are very much in favor of the PEM paradigm and instrument, but would like to develop a way of highlighting the infant's contribution and involvement through a method, or more precisely, an eye-opener, that can easily be put into use. The narrative method, as described above, is all about telling stories and diving hermeneutically into those stories about the infant and the interaction. For instance, it can be made as a specific layout, where a professional interacting with an infant, directly afterward compose a narrative about the infant and the interaction, and with the help of a colleague or two, interprets the narrative, looking for the infant's voice in the "provocations" emerging between them.

CONCLUSION

Let us end with a quote from Delafield-Butt and Trevarthen (2015, p. 13), ending their article in *Frontiers in Psychology* like this: "Thus life stories with their intrinsic narrative vitality create a store of experience, memories, understanding and purpose–the culture of a cooperative society." One major cooperative society–the United Nations, has a Convention for the rights of the child. This convention asks for a definite way of involving infants, the youngest citizens, and to let them use their narrative vitality to create in our culture a store of experience, memories, understanding and purpose. The only thing we as grownups have to do, is to lend them our minds and bodies, to use in the symbolization and transformation of their narratives into verbal language and constructive action on their behalf. If we understand, respect and believe in the foundational structures of intersubjective communication, we should take very seriously telling stories or singing songs about our infant members of society. Their participation, their voice, can surface in our verbal or musical narratives, and we should help each other to find them there.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

Both authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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Neonatal Imitation, Intersubjectivity, and Children With Atypical Development: Do Observations on Autism and Down Syndrome Change Our Understanding?

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Almost all studies on neonatal imitation to date seem to have focused on typically developing children, and we thus lack information on the early imitative abilities of children who follow atypical developmental trajectories. From both practical and theoretical perspectives, these abilities might be relevant to study in children who develop a neuropsychiatric diagnosis later on or in infants who later show impaired ability to imitate. Theoretical in the sense that it will provide insight into the earliest signs of intersubjectivity—i.e., primary intersubjectivity—and how this knowledge might influence our understanding of children following atypical trajectories of development. Practical in the sense that it might lead to earlier detection of certain disabilities. In the present work, we screen the literature for empirical studies on neonatal imitation in children with an Autism spectrum disorder (ASD) or Down syndrome (DS) as well as present an observation of neonatal imitation in an infant that later was diagnosed with autism and a re-interpretation of previously published data on the phenomenon in a small group of infants with DS. Our findings suggest that the empirical observations to date are too few to draw any definite conclusions but that the existing data suggests that neonatal imitation can be observed both in children with ASD and in children with DS. Thus, neonatal imitation might not represent a useful predictor of a developmental deficit. Based on current theoretical perspectives advocating that neonatal imitation is a marker of primary intersubjectivity, we propose tentatively that an ability to engage in purposeful exchanges with another human being exists in these populations from birth.

Keywords: neonatal imitation, primary intersubjectivity, autism spectrum disorder, down syndrome, literature search

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INTRODUCTION, THEORY, AND MOTIVATION

Most published studies on imitation during the first months of life have focused on typically developing children. It might actually be *all* studies for imitation of facial gestures during the neonatal period. Researchers seem to avoid including children with any known risk factors for non-optimal development. It follows that reports often state that the children included in studies on neonatal imitation were born full-term and did not have any known medical complications.

However, if imitation in the neonatal period is a real phenomenon affecting early social interaction and development, it becomes of uttermost importance to also investigate if children who show developmental deviances, either specifically in the social domain or more generally, differ from typically developing children in this ability. Here we present: (i) a comprehensive literature search focusing on published reports on imitation during the first year of life in children with an Autism Spectrum Disorder (ASD) or Down syndrome (DS); (ii) a home video observation that in our view might be interpreted as showing imitation during the neonatal period in a child later diagnosed with autism; and, (iii) a re-representation of previously published data on near-neonatal imitation in children with Down syndrome, observations that hitherto has gone largely unnoticed by the scientific community (Heimann et al., 1998).

The observation that infants might imitate already as newborns has been with us for a long time, and this ability has been reported by numerous studies since the 1970's (e.g., Meltzoff and Moore, 1977, 1983, 1989; Dunkeld, 1979; Maratos, 1982; Heimann and Schaller, 1985; Heimann et al., 1989; Kugiumutzakis, 1998; Nagy et al., 2013; for a recent meta-analysis, see Davis et al., 2021). Importantly, the existence of this phenomenon has been argued to reflect a rudimentary capacity for primary or innate intersubjectivity (i.e., Trevarthen, 1979, 2011a), that is, an ability to engage in intentional and purposeful exchanges with another human being (e.g., Trevarthen and Aitken, 2003; Rochat and Passos-Ferreira, 2009; Trevarthen, 2011a,b). Although we acknowledge the current debate around how to understand a newborn child's imitative-like responses (e.g., Oostenbroek et al., 2016; Jones, 2017), this paper rests on the assumption that those responses are best described as an act of neonatal imitation (e.g., Simpson et al., 2014; Meltzoff et al., 2018; Heimann and Tjus, 2019). In line with this, we also assume that this early act of imitation reflects a potential expression of primary intersubjectivity and that we need a better understanding of its place in development for children following both typical and atypical developmental pathways. Our hypothesis that newborn imitation is an example of an early social motive that signifies an intersubjective capacity is furthermore anchored in the works by several different theoreticians over the years (e.g., Bråten, 1998; Reddy, 2008; Rochat and Passos-Ferreira, 2009), but foremost on Trevarthen's groundbreaking ideas as exemplified in these two quotes:

> "Most remarkably, before a baby has competence for handling and exploring non-living objects, he or she shows sensitive awareness of the motive states and feelings of other persons who offer to interact in well-timed contingency with what the infants expresses, and the baby reacts in intricately adaptive interpersonal ways to human expressions, often imitating, but not just by imitating." (Trevarthen and Aitken, 2003, p. 112).
>
> "Infant human beings imitate other humans, not just to act like them, but to enter into a communicative and cooperative relationship with them by some transfer of the feeling of body action...They can, in this way, start building understandings that may serve later to identify a particular companion in the meaning of a shared world" (Trevarthen, 2011a, p. 124).

If neonatal imitation is one of the first signs of innate or primary intersubjectivity as proposed by Trevarthen (1979, 2011b), Bråten (1998), Reddy (2008), and Kugiumutzakis and Trevarthen (2015), then the question also arises to what degree children following an atypical developmental trajectory would show an early imitative ability. In other words: Is this capacity of the neonate associated primarily with typical development, or is it an ability that also can be observed among infants, following an atypical developmental trajectory?

For autism, imitation has often been highlighted as one of the capacities that develops slowly and possibly represents a core deficit (Sigman et al., 2004; Volkmar et al., 2005; Nadel, 2006, 2014; Rogers, 2006; Vanvuchelen et al., 2011; Gowen, 2012; Vivanti and Hamilton, 2014). Imitation has been viewed as important for children with ASD because it "supports a sense of interpersonal connectedness and mutuality" (Sigman et al., 2004; p. 224), capacities that people with autism often find difficult. This aspect plus the fact that imitation is an important tool for learning through observation have made imitation training an important part of various training and intervention programs for children with autism (see Schreibman et al., 2015; Spjut Jansson et al., 2020). As one central example, Rogers and Pennington (1991) included imitation as one of the early deficits in their theory on autism. According to them, neonatal imitation is an early social competence that would be missing in newborn children that later develop autism. In a subsequent theoretical attempt, Heimann (1998) outlined two possible developmental routes for children with autism. Building on Bråten's (1988, 1998) theoretical formulations that, from the beginning, the mind is both dialogical and intersubjective, two hypothetical models of development were formulated (see **Figure 1**).

Heimann (1998) reasoned that neonatal imitation, as a marker of primary intersubjectivity, may or may not be observable in infants who later show signs of autism or other developmental disabilities. In one scenario, neonatal imitation is linked to more advanced imitation and intersubjective abilities at later stages in development, which leads to the expectation that neonatal imitation should be impaired in infants with ASD. Thus, a diminished imitation ability in a neonate might be a sign of an unfulfilled capacity to partake in early intersubjective social encounters. A second scenario noted by Heimann (1998) is that neonatal imitation might not have a direct relationship to later imitative ability and intersubjective development. In this scenario, neonatal imitation might be observable in infants with autism or other developmental disorders that are associated with impairments in the social domain. This could mean that mechanisms for primary intersubjectivity are not impaired from birth in these populations and, instead, that atypicality in relating to another person emerges later as other layers of intersubjectivity develop.

One problem in determining whether a lack of the ability for neonatal imitation is an early marker of autism is that the condition is not usually diagnosed before the child is several years old and rarely before 2 years of age (Ozonoff et al., 2015; Goldstein and Ozonoff, 2018; Zwaigenbaum et al., 2020). Even if many parents report retrospectively that they did note problems

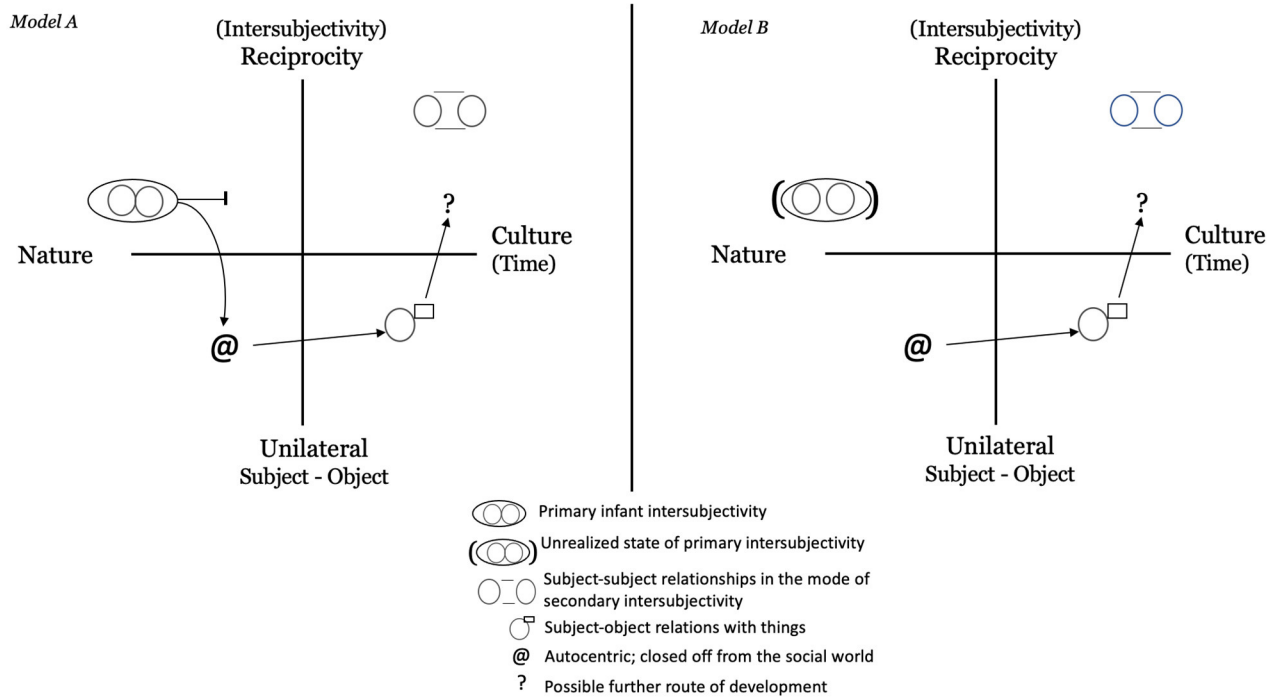

FIGURE 1 | Two theoretical models describing the infants state of mind with respect to intersubjectivity at birth for a child later diagnosed with autism. *Explanations: Model A* describes an initially typical development, the infant is born with a capacity of primary intersubjectivity, autism emerges later. *Model B* describes a starting state that is different from the beginning. A child within the autism spectrum does not have the same capacity to intersubjectivity at birth, the mind is not dialogical from the start (Adopted from Heimann, 1998, p. 100–101. Reprinted with permission).

during the first year of life, it has not been possible to pinpoint an exact cluster of behaviors that makes it possible to reach a definite diagnosis early in life (but see Wetherby et al., 2021 for an early identification protocol). An additional problem is that some children with autism show a typical developmental trajectory from birth to about 12 or 18 months of age whereafter they start to lose abilities (Ozonoff et al., 2008). An example of such a regressive pattern might be a child who, after being able to point and utter his or her first words, suddenly stops both pointing and talking.

Davis and Crompton (2021) highlight the growing insight that the social difficulties associated with autism or other neurodiverse conditions "are at least in part bidirectional" (p. 652). They also argue for researchers to use a difference perspective, in contrast to the more traditional deficit model. This leads to the need for a research framework that charters socio-cognitive abilities in detail and that avoids preconceived expectations of what to expect or not to expect from autistic people or other neurodiverse groups. Within the scope of this paper, this means that we must acquire a better knowledge of the competencies of, for example, infants with the risk of developing autism. If we ever will be able to understand how the different social and communicative abilities of autistic persons evolve, we must differentiate between problems residing within the individual from problems arising from "a mismatch of interpersonal dynamics" (Davis and Crompton, 2021; p 650), as proposed by the dialectical mismatch hypotheses (Bolis et al., 2017).

For children with DS, early development differs from most children with autism (although the two syndromes can also overlap). DS is a chromosomal aberration usually diagnosed at birth or shortly thereafter and almost all children with this syndrome end up having a mild to moderate intellectual disability (Udwin and Dennis, 1995; Di Nuovo and Buono, 2011; Ostermaier, 2019). Since the diagnosis is made early, one would have expected that some studies on imitation at birth or shortly thereafter in this group would have been conducted. But this seems not to be the case. One of the few comprehensive and longitudinal studies of the early psychological development focusing on children with DS is the study by Dunst (1990) that describes sensorimotor development over the first 3 years of life.

The mean age of the nine children constituting the youngest group in Dunst's sample was 2.9 months, and they displayed an almost typical level of imitation according to the Uzgiris-Hunt scale (Uzgiris and Hunt, 1975). However, imitation of facial gestures like tongue protrusion or mouth opening used in studies of imitation in newborn children were not included. Dunst used Piaget's theory when chartering the early development of children with DS and concluded that this group follows a similar developmental trajectory as typical children, although at a slower rate. The development of the youngest group,

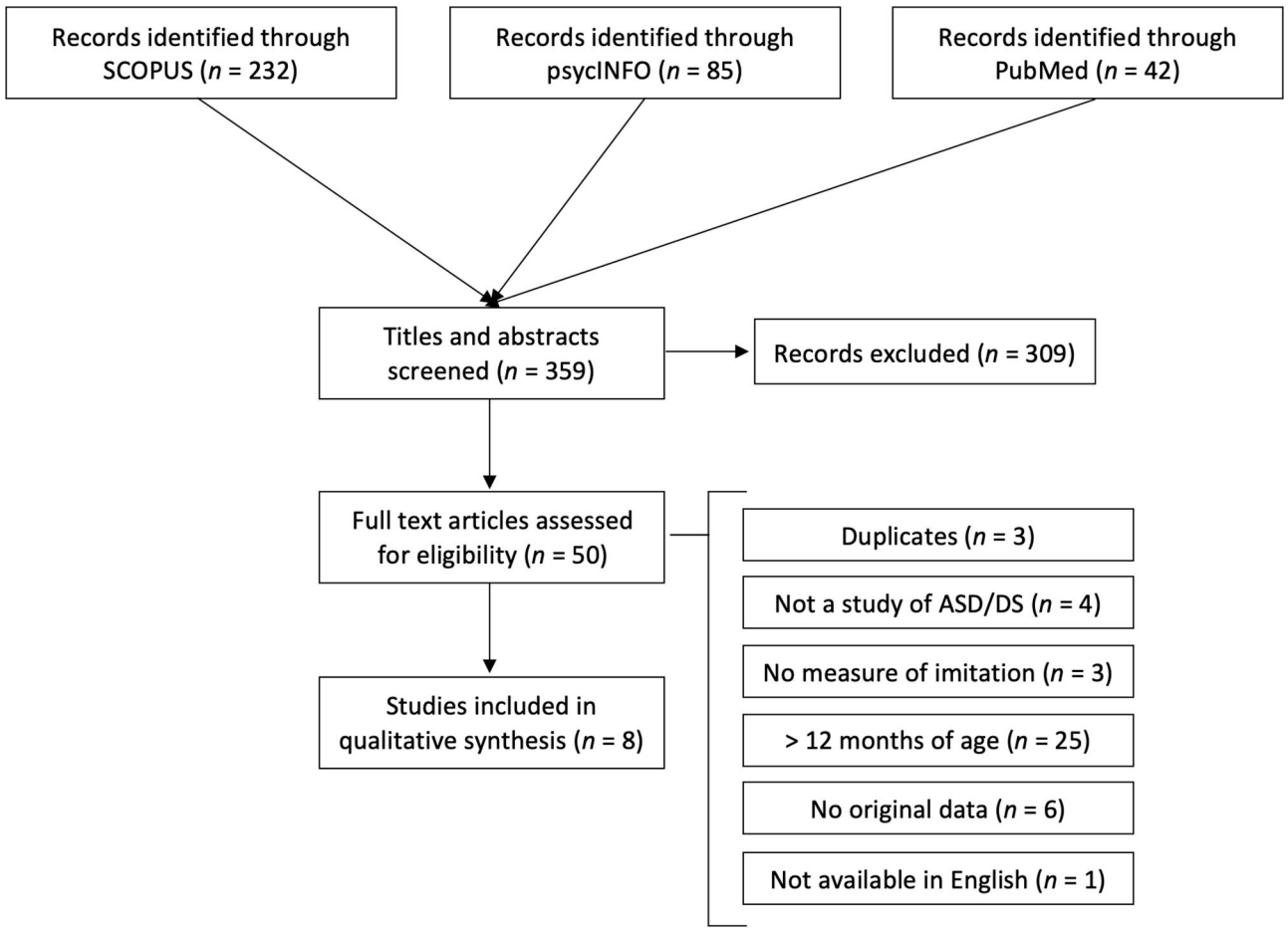

FIGURE 2 | Flow diagram of the literature search.

children younger than 4 months, was almost on par with typical infants (Dunst reported a developmental quotient of 85), but they were clearly below average when they reached their first birthday (DQ = 62). This "slowing down phenomena was most pronounced for vocal imitation" according to Dunst (1990; p. 224).

While studies on neonatal imitation in humans to date have almost exclusively focused on healthy infants (e.g., Meltzoff et al., 2018; Davis et al., 2021), our goal is to provide observations relevant for children developing along atypical trajectories that might affect how the capacity for primary intersubjectivity develops. We will do this through three different paths presented as three different studies:

1. A search through scientific databases for papers on imitation in infants at-risk for ASD and/or DS during the first year of life with a primary focus on the neonatal period or early infancy up to 3 months of age;
2. Presenting tentative observations from a brief home video on imitation-like responses in a neonate developing along an autism trajectory; and
3. In a re-use of published findings, we present a more in-depth analysis of how five one-month-old children with DS respond in an imitation experiment.

STUDY 1. LITERATURE SEARCH

The psycINFO, PubMed, and Scopus databases were searched for publications in English on the topic of imitation in populations with DS or ASD younger than 2 years of age. Searches of articles were conducted by the second author (E.H.) on December 3, 2020, in psycINFO and PubMed, and on February 26, 2021, in Scopus (for search terms and limiters, see **Supplementary Materials**). We did not set any limit for publication date.

A flow diagram of the search including the four phases recommended by Liberati et al. (2009) is presented in **Figure 2**. The search resulted in 85 records in psycINFO, 42 in PubMed, and 232 in Scopus. After review of titles and abstracts, 50 records were kept for full-text review. The most common reason for exclusion was that the publication was not a study of imitation (e.g., mimicry of medical conditions), studied a

non-human population (e.g., rodents), or included participants that were older than the targeted populations. Full-text records were reviewed for inclusion independently by both authors. Inclusion criteria were that the publication described an original empirical study with at least one imitation task (e.g., experimental procedure, observational methods, behavioral ratings), and included participants with DS or ASD that were younger than 12 months of age.

After full-text reviews, four articles were deemed eligible for inclusion by both authors, and we agreed to reassess an additional five articles due to uncertainties in study design. Four of these five articles were included after reassessment, and both authors agreed on excluding the fifth. The reasons for exclusion are listed in **Figure 2**. The eight articles kept for this review are described in **Table 1**.

Studies included children with DS ($n = 2$), ASD ($n = 4$), or children from a high-risk population for ASD (i.e., younger sibling to a child with an ASD, $n = 2$). The earliest measure of imitation that was reported was from an age of 1 month, and the same participants were also observed at 3 and 4 months of age (Heimann et al., 1998). Age spans in the rest of the studies were in the range of 6–11 months. The largest study included 86 children with a diagnosis, and the smallest was a single-case study. Two studies reported results from an intervention, with baseline measures of spontaneous imitation in mother-child interaction, while the other studies used parental questionnaire ($n = 1$), notes from medical records ($n = 1$), or experimental procedures ($n = 3$). Four of the studies had a control or comparison group, and one of these (Keemink et al., 2021) reported that 6–9-month-old-infants at high-risk for ASD were less likely than a control group to spontaneously imitate facial emotion expressions; in the three other studies, no between-group differences were detected under the age of 12 months.

STUDY 2. IMITATION IN A 3-DAY OLD CHILD LATER DIAGNOSED AS AUTISTIC

The following text tells the story of Marcus, a boy with ASD. When he was 3-days old, his parents used a smartphone to take a video of him as parents often do, and Marcus' mother later provided this home video to the first author (M.H.). The very brief home video shows the father modeling tongue protrusion and how Marcus responds. Marcus received an autism diagnosis before his third birthday, and his story is briefly described in this section.

Birth and Early Development

Marcus was born at term (gestational age: 38 weeks). His birthweight was within the expected range (3,030 g) and there were no signs of asphyxia or other immediate complications. In fact, his Apgar scores were perfect (10, 10, 10). However, the pregnancy had not been uncomplicated. His mother had spent some periods in the hospital due to infections and pneumonia. In spite of his perfect Apgar scores, Marcus was diagnosed with serious complications a couple of hours after birth: early onset GBS sepsis (Group B streptococcal septicemia), a condition that can seriously influence a child's health and further development (Libster et al., 2012).

After treatment and a prolonged stay in the hospital before the parents were allowed to take him home, Marcus seemed to develop as expected during his first year of life. The parents were acquainted with what to expect from a child during the first year of life (Marcus was their third child), and they did not note any atypical signs early on. He made adequate eye contact according to his mother, he developed pointing as expected, and he uttered his first word before his first birthday. However, the situation changed shortly after his first birthday. It became more and more difficult to maintain eye contact with him, and his interest in other people decreased sharply. Parallel to this, he became less verbal, and eventually he stopped talking. Instead, he became more focused on objects, puzzles, and YouTube video clips. These behavioral changes began to worry his parents and, when he was 19 months old, his mother found a screening instrument online, the Modified Checklist for Autism in Toddlers (MCHAT; Robins et al., 2001). She answered the items in the checklist and received a score of 21 out of 23 with the following summary and recommendation: "This score suggests that your toddler is at elevated risk for autism or another developmental disorder and should be evaluated by a specialist for early intervention services."

First Clinical Evaluation and Diagnosis

The family contacted the health services who referred them to a neuropsychiatric clinic that initiated an evaluation shortly before Marcus' second birthday. The team was made up by a child psychiatrist, neuropsychologist, speech and hearing therapist, and a special education teacher. Some excerpts from the neuropsychological and medical examination provides a good context for understanding the grounds for his diagnosis:

The psychologist notes that Marcus speaks no words and does not use gestures but is able to clearly express both joy and when he dislikes something. He is easily frustrated, but it is relatively easy to get him back on track. He does not initiate any interaction and does not respond to any invitation. He uses his mother's hand when needing any help. The psychologist also notes that he gives eye contact only once during the whole assessment.

The psychologist used mainly two instruments during this initial assessment: Vineland Adaptive Behavior Scales II (Sparrow et al., 2005), a parental questionnaire, and a developmental test, the Griffiths Scale of Child Development I (Alin-Åkerman and Nordberg, 1983). The results from Griffiths can be translated into age equivalents (AE) indicating the age level that corresponds to the responses a child gives. Marcus is 24 months old when evaluated, and the result is an uneven profile. His scores are close to his biological age within three of the areas included in the Griffiths test: the gross motor, eye-hand coordination, and performance scales (AE's 17–22 months). In contrast, he shows a clearly protracted development on the two scales sensitive to language, communication, and social development (AE's 6 ½ and 11 ½ months). The result from the Vineland parental interview showed that Marcus' adaptive abilities were affected. His most severe problem area was his communicative abilities whereas his motor abilities were judged to be at age level.

TABLE 1 | Description of identified articles in the literature search.

Study	*N*	Participant description	Imitation assessment	Imitation results
Autism spectrum disorder				
Bolton et al. (2012)	86	Children diagnosed with autism spectrum disorder at 11 years of age. Participants were part of a large sample ($N = 14,541$) followed from the age of 6 months.	Parental questionnaire at 6 and 11 months.	Responses to questions referring to imitation/play at age 6 months was not a significant predictor of diagnosis at age 11 years. Potentially a predictor of later degree of autistic trait (but overlap between instruments).
Dawson et al. (2000)	1	A boy diagnosed with autism spectrum disorder at 1 year of age (assessed on the Autism Diagnostic Interview, Lord et al., 1994). First notes/observations at 2.5 months of age.	Notes from medical journal at 9 months.	Notes suggesting that the child does not play imitation games with parents.
Keemink et al. (2021)	18	Infants (11 boys) with at least one older sibling who had an autism spectrum disorder diagnosis. Six participants were 6 months old and 12 were 9 months old.	Participants and controls performed a gaze-contingency task, looking at faces that turned from a neutral expression to an emotional. Spontaneous imitation in response to emotional facial expressions was coded.	Participants were less likely to imitate facial emotion expressions than the control group.
Neimy et al. (2020)	3	Infants (one boy) aged 7, 8, and 11 months, with at least one older sibling who had an autism spectrum disorder.	During a baseline before the introduction of an intervention, vocal imitation ("echoics") was coded based on video observation of interactions between the mother and the child.	One child showed evidence of vocal imitation during baseline.
Receveur et al. (2005)	18	Children (13 boys) diagnosed with autism spectrum disorder after the age of 4 years, and split into two groups based on high ($n = 8$)/low ($n = 10$) developmental quotient (as indicated by a score above/below 50 on the Brunet-Lezine Scales, Brunet and Lezine, 1983). Observations started at 10–12 months.	Participants were filmed by their parents during the two first year of life. Imitation was scored by using the Imitation Disorder Evaluation scale (Malvy et al., 1999) on video observations.	At 10–12 months, there was no difference in imitation score between children with high and low developmental quotient.
Sanefuji and Yamamoto (2014)	21	Children (16 boys) with scores above cut-off for autism spectrum disorder on ADOS (Lord et al., 1989) at 24 months. Participants were part of a larger sample of 54 high-risk children (i.e., younger siblings of children with an autism spectrum disorder). First observation at 11 months.	Imitation ability was assessed on experimental tasks, including object manipulation (Meltzoff, 1988), gesture imitation (Smith and Bryson, 2007), and movement imitation (Bekkering et al., 2000; Rogers et al., 2003).	At 11 months of age, no statistically significant differences were observed between participants above the cut-off on ADOS at 24 months compared to those below.
Down syndrome				
Heimann et al. (1998)	8	Infants (7 boys) diagnosed with Down syndrome. Successful testing performed at 1 ($n = 5$), 3 ($n = 7$), and 4 ($n = 7$) months of age.	Tongue protrusion and mouth opening were presented to the infant by an experimenter and responses were video recorded. Imitation was coded from videos, defined as a matching response that exceeded the observed rate of non-matching responses.	Evidence of imitation of tongue protrusion but not mouth opening was reported at 1 month of age. At 3 and 4 months of age, no evidence of imitation was observed at the group level, although some individuals imitated either tongue protrusion or mouth opening.
Bauer and Jones (2015)	3	Infants (2 boys) with Down syndrome, aged 7, 8, and 9 months.	During a baseline before the introduction of an intervention, an experimenter produced vocal utterances that the infant was prompted to imitate (e.g., "Say, 'mmm'."). Imitation was assessed from video recordings, was coded based on video observation of interactions between the mother and the child.	Two infants showed limited evidence of vocal imitation during baseline.

TABLE 2 | The criteria for an autism diagnosis according to DSM-IV-TR that Marcus fulfilled according to the clinical evaluation.

	Abridged DSM-IV criteria for autism		Marcus' evaluation
1.	*Qualitative impairment in social interaction*[a]		
	a. impairment in the use of non-verbal behaviors (e.g., eye-to-eye gaze)	Yes	
	b. failure to develop peer relationships	Yes	
	c. lack of sharing enjoyments with other people	Yes	
	d. lack of social/emotional reciprocity	Yes	
2.	*Qualitative impairments in communication*[b]		
	a. delay or lack of development of spoken language	Yes	
	b. inability to initiate conversations		No
	c. idiosyncratic use of language		No
	d. lack of pretend play or imitative play	Yes	
3.	*Restricted patterns of behavior, interests, and activities*[b]		
	a. preoccupation with restricted pattern of interest	Yes	
	b. inflexible adherence to routines	Yes	
	c. stereotyped motor mannerisms (e.g., hand flapping)	Yes	
	d. preoccupation with parts of objects		No

[a] *Two criteria must be met;* [b] *At least one criterion must be met.*

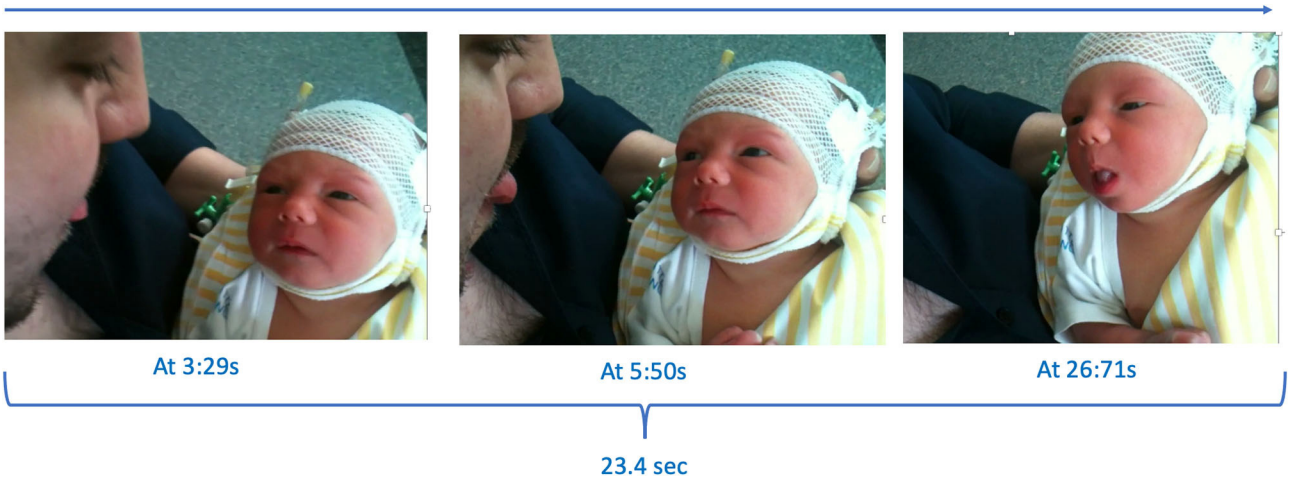

FIGURE 3 | A sequence of still photos (courtesy of the family) from the home video showing Marcus' response. Tongue protrusion is defined as a clear forward movement of the tongue even if the tongue was not protruded beyond the outer part of the lips (see Heimann and Tjus, 2019).

The result from the psychological evaluation is confirmed both by the detailed analysis of his language and communicative development conducted by the speech and language therapist and by evaluation with the Autism Diagnostic Observation Schedule (ADOS; Lord et al., 1989, 2000) performed by the special education teacher. The Children's Global Assessment Scale (C-GAS) (Shaffer et al., 1983; Lundh et al., 2010) was added by the child psychiatrist. Marcus received a score of 38 which indicates "major impairment in functioning in several areas and unable to function in one of these areas" (e.g., at home, in preschool or with peers; Shaffer et al., 1983, p. 1229). In conclusion, the child psychiatrist sees the same pattern as his team members and concludes that Marcus fulfills the criteria for classic autism and intellectual disability according to DSM-IV-TR (American Psychiatric Association, 2000) and ICD-10 (World Health Organization, 1990). Specifically, the child psychiatric evaluation established that Marcus fulfilled all DSM-IV-TR criteria for qualitative impairment in social interaction, two out of four criteria for qualitative impairments in communication, and three out of the four criteria listed for repetitive and stereotyped patterns of behavior (American Psychiatric Association, 2000, see **Table 2**).

Home Video Suggesting a Capacity to Imitate

When Marcus was 3 days old, his mother used her smartphone to take photos and some brief videos of him together with his father. One of these videos show the father sticking out his

TABLE 3 | A sequential overview of the home video showing Marcus responding with tongue protrusion (TP) to his fathers' modeling.

Timeline[a] (s)	Father (model)	Marcus (response)[b]
0	Looks at Marcus	Looks slightly away
3	Presents first TP	Looks at F
6	Second TP	↓
8	Third TP	
10	Looks at Marcus	Eyes closed
12	↓	Looks at F
13	Fourth TP	↓
15	Looks at Marcus	Looks away
18	Fifth TP	Looks at F
22	Sixth TP	↓
23	Looks at Marcus	TP
25	↓	TP
26		TP
27	Smiles	Looks away

[a]*Time averaged to whole seconds;* [b]*TP defined as a clear forward movement of the tongue even if the tongue was not protruded beyond the outer part of the lips.*

tongue when holding Marcus, who seems both calm and attentive although slow in his movements. The segment is only about 30 s long (see **Figure 3** and **Table 3**), during which his father presents six tongue protrusions and Marcus responds with three. The criteria for judging tongue protrusion in this case follows earlier publications by accepting as a minimum criterion that a clear forward movement of the tongue is noted although the tongue might not be protruded beyond the back edge of the lower lip (e.g., Meltzoff and Moore, 1983; Oostenbroek et al., 2016; Heimann and Tjus, 2019). Marcus responses were coded by the first author (M.H.) and independently by two other researchers. No statistical analysis was possible since there was no control gesture presented to Marcus and no section of the video that could be used as a possible baseline measure.

Discussion

We acknowledge that this is anecdotal evidence that must be interpreted with much caution (see Ozonoff et al., 2011, for a comparison between home videos and clinical evaluations), but it is notable from the video that Marcus shows no other facial movements, such as mouth opening, during this brief episode. His first response is a tongue protrusion that comes more than 20 s after his father protruded his tongue for the first time. Regardless if we define Marcus' response as imitation or not, the video does show that a 3-day old infant later diagnosed with autism is able to match tongue protrusion. And he does so in a way that, in many aspects, mimics how neonatal imitation of facial gestures has been studied and described in published studies (e.g., Heimann and Tjus, 2019). If neonatal imitation is linked with later imitation and social responsiveness, this observation suggests that it is probably not a direct link–at least not so for children with autism since imitation is a skill that often is part of the initial training used in comprehensive preschool behavioral training programs for children with autism (e.g., Vismara and Rogers, 2010; Ingersoll and Meyer, 2011; Spjut Jansson et al., 2020). Furthermore, if we take the observation as a true sign of neonatal imitation, then it suggests that a child with autism (maybe all children with autism), who we know have a different and problematic relationship with the social world as they develop, might be no less social as newborns than "typically" developing children.

STUDY 3. IMITATION IN ONE-MONTH OLD INFANTS WITH DOWN SYNDROME

Background

There seems to be a dearth of studies on the socio-cognitive abilities of children with DS at birth, as evident from the literature search described above. We could not identify a single study investigating imitation among infants with DS during their first 2–3 weeks of life. The only study that came close was conducted by one of the authors (M. H.) more than 20 years ago (Heimann et al., 1998) with the goal to study facial imitation over the first 3 months in an attempt to parallel previous published observations on typical infants.

The initial plan, when the study was conceived in the 1990's, had been to carry out the first observation when the children were still within the neonatal period, that is, before 1 month of age. However, due to both medical and psychological reasons, this became impossible. Children with DS often require extra medical support and/or evaluations directly after birth. For the parents, even if they might have known beforehand that their expecting child had DS, the early neonatal period usually becomes a time of adjustment when focus is on other issues than research. In the end, we succeeded to recruit a group of eight children with DS (see Heimann et al., 1998) born between gestational weeks 36–39 ($Mdn = 39$) and, for five of them, we were able to conduct the first observation close to the neonatal period when they on average were 37 days old ($SD = 11.0$; range 25–52). The focus here will be only on the five children (all male) observed around 1 month of age.

Method

All observations took place in the home of the children using light-weight portable video equipment. The parents were often present in the room during the observation and the sessions did not begin until the child was judged to be awake and alert. TP or MO were presented to the child by an experimenter and all gestures were presented during a pre-set interval of 20 s followed by a response time of equal length. This sequence was repeated three times, giving each child a total observation time of 120 s ($M = 122.1$ s; $SD = 9.4$). The order of presentation was randomized, and the experimenter did not know beforehand which gesture to start with. By definition a TP occurred whenever a clear forward movement was detected, even if the tongue only passed the posterior part of the lip (similar to the definition used for Marcus in the previous section). MO "was defined as a clear and visible separation of the lips that was judged to meet the criteria of a definite change. Some children kept their mouths open over extended periods of time which was not accepted as a MO. A clear change had to take place" (Heimann et al., 1998;

p. 781). Furthermore, no concurrent forward trust of the tongue was accepted nor was yawning. All videos were coded blindly by two research assistants and the obtained Kappa coefficient was 0.92. Imitation was defined behaviorally: an individual child was judged to imitate if the frequency of matching responses exceeded the observed number of non-matching responses.

Results

We conducted three separate analyses: (1) the overall result across the complete 2-min period; (2) the result for the three modeling periods; and (3) the result for the three response periods. Based on the current knowledge at the time when the study was conducted (in the 1990's) that children with DS develop "in the same sequence as that followed by normal children" (Hodapp and Zigler, 1990; p. 10), we hypothesized that we would find that our DS group displayed imitation similar to what had been observed for typical children. Statistically we used two-tailed tests (Wilcoxon and sign test).

We found support for imitative-like responses when the whole period and the modeling periods were analyzed but not when focusing only on the response periods (Heimann et al., 1998). The most convincing indication of imitation was found when only the modeling periods were analyzed (see **Figure 4**). The frequency of TP increased on average with 2.3 responses (range 1.2–3.8) when TP was modeled in comparison with the observed frequency of TP when modeling mouth opening (Sign test; $z = 2.23$; $p = 0.025$, Wilcoxon; $z = 2.02$; $p < 0.05$). The pattern for MO was similar, the frequency of MO increased with on average 4.0 mouth openings (range 1.6–7.4) when MO was modeled in comparison with the number of MOs observed after modeling of TP (Sign test; $z = 2.00$; $p = 0.046$; Wilcoxon; $z = -1.75$, $p = 0.08$).

Individually, all five children imitated TP during modeling. The pattern for MO was slightly different, four of the children imitated, while the fifth child displayed a pattern of no change, the frequency of MO stayed the same in both conditions. Putting it differently, none of the children responded with what could be described as a contra-imitative pattern, for instance displaying the highest frequency of MO when TP is modeled. At least not when only the modeling periods were analyzed.

Discussion

Even if this small study indicates that infants with DS seems able to display near-neonatal imitation under some conditions it is worth noting that the children responded a bit different to what we had previously observed for typical infants (Heimann et al., 1989; Heimann and Tjus, 2019). Their mean rate of responses, especially so for TP, often exceeded what we have previously observed for infants during the neonatal period (Heimann et al., 1998). Furthermore, the different result for the modeling and response periods tentatively suggests that children with DS are helped by having stimuli in sight in order to respond. When the modeling stops and the response period start, they lose focus and fail to differentiate their response.

It is not possible to generalize or draw any definite conclusions from a study of only five infants. Despite this and the fact that children with DS might be an even more heterogenous group than typical infants, the findings from the 1-month-old observation are relatively straightforward. During the periods when the gestures were actively modeled all five children imitated TP and four out of five MO. No child displayed a strong non-imitative pattern of increasing the frequency of the control gesture (e.g., TP) in comparison with the gesture being modeled (e.g., MO). The only child not imitating showed no change, he opened his mouth an equal number of times both when MO and TP were modeled. The paper on which this summary is based did "conclude that children with Down syndrome show an early capacity for imitation similar to that usually expected for normal infants during the first few weeks of life" (Heimann et al., 1998; p. 783). Today we would also cautiously propose that children with DS show signs of a dialogical mind (Bråten, 1988) and a capacity for primary intersubjectivity (Trevarthen, 2011a) already at 1 months of age. We do however not know if this ability is there already at birth or not.

GENERAL DISCUSSION

The aim of this endeavor has been to explore what is known from empirical studies on the existence of imitation or imitation-like responses near birth or during the first year of life among children with non-typical trajectories. We have done this through three different venues: by searching published reports via three different databases; by presenting a previously unpublished observation on facial imitation in a 3-day-old infant that later received an ASD diagnosis; and finally by a renewed presentation of previously published observations on imitation in five 1-month-old children with DS. Based on the observations reported here, we tentatively propose that the little empirical evidence that exist implies that children with ASD and DS have a similar capacity for neonatal imitation as do typically developing children and, thus, an innate capacity for primary intersubjectivity. However, our most critical suggestion is that there is a great need of studies investigating neonatal imitation in atypical populations.

Searching Scopus, PubMed, and PsycInfo for papers on neonatal imitation in atypical populations resulted in 50 papers receiving a full-text review, of which 42 were excluded in the end for not fulfilling our criteria (e.g., focused on diseases, non-human populations, or included participants older than 12 months). Of the eight articles included, only two focused on DS, and the only article that described development from birth in a case of a boy with ASD did not comment on imitation before the age of 9 months (Dawson et al., 2000). The one article describing imitation around the first month of life was the one by the first author on this paper (M.H.), described in detail above. Thus, our literature search shows that almost no empirical research on neonatal imitation exists in the target populations of this paper. This is particularly surprising in the case of ASD, since imitation is assumed to be impaired in this population and a possible precursor of later deviant social development (Rogers and Pennington, 1991; Vanvuchelen et al., 2011). The only documented observation that we have been able to identify is the case of Marcus described in this paper and based on that, we do not currently see any support for the hypothesis that imitation

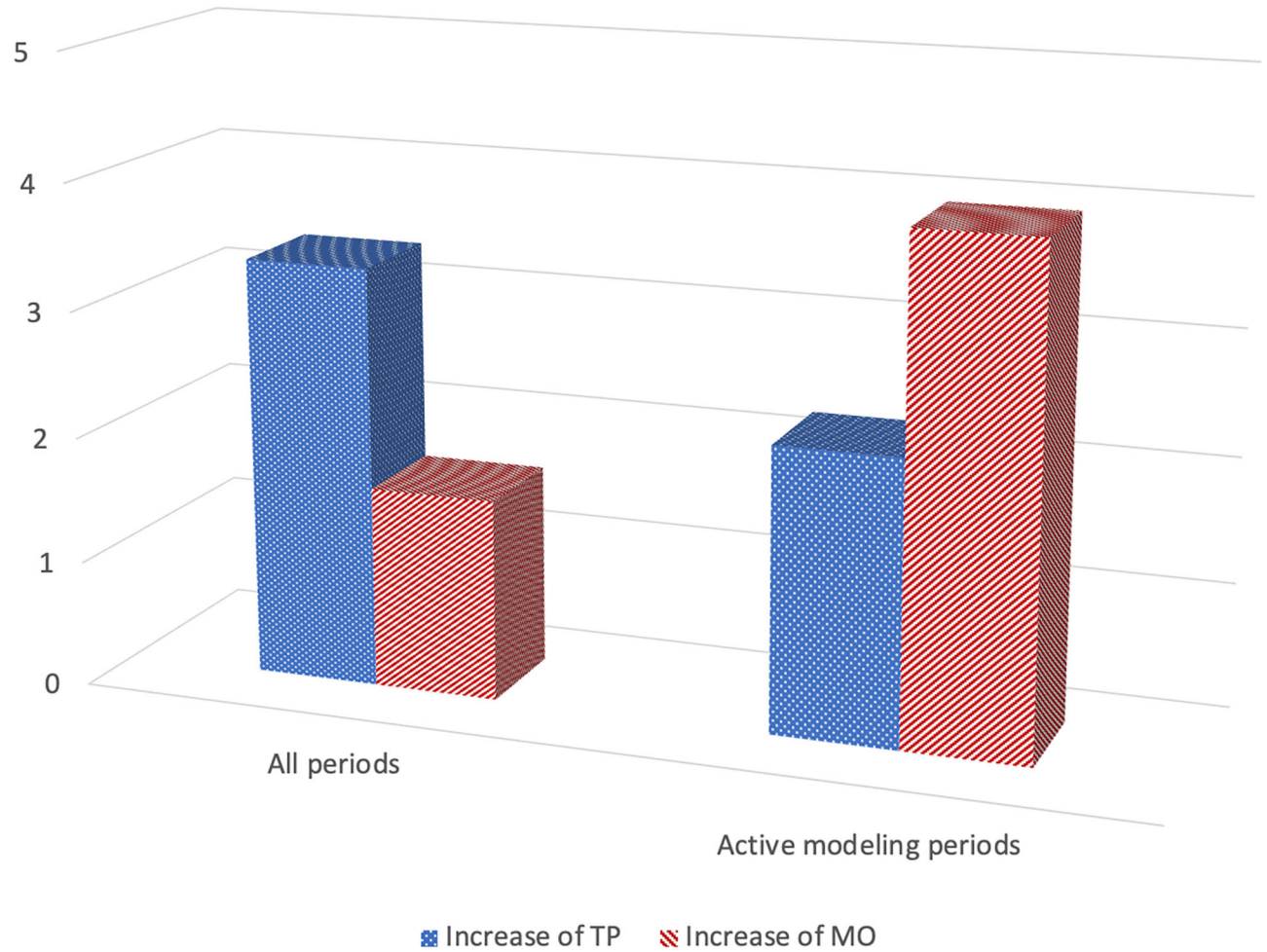

FIGURE 4 | Imitation in infants with Down syndrome ($N = 5$) at 1 months of age: Mean rate increase of tongue protrusion (TP) and mouth opening (MO) after modeling of each gesture during all periods of the experiment (6 × 20 s) as well as only during the active modeling periods (3 × 20 s). See text for more details (based on Heimann et al., 1998, Tables 3, 4).

is absent in the neonatal period for children on the track to develop ASD. Clearly, more research is highly needed to test this assumption.

For ASD, the home video of Marcus imitating TP when only 3-days-old raises questions about the starting state of a child developing along an autistic path. True, it is only anecdotal evidence based on a very brief video. But even as such, the observation challenges our knowledge of how ASD develops over time. One might argue that Marcus is unique and that the observation says very little about children with ASD overall. Still, to our knowledge this is the first documented observation of its kind. It has, for instance, direct bearing on the two models based on Bråten's theory (Bråten, 1988, 1998) that Heimann (1998) outlined. Based on the video of Marcus, we suggest that Model B should be dismissed in favor of Model A, which, by allowing for an initial state of primary intersubjectivity, probably is closer to the truth. However, even this model is limited since it does not take the heterogeneity of autism into account (see Fountain et al., 2012; Georgiades et al., 2013; Mottron and Bzdok, 2020). We therefore suggest an updated model, Model C, as illustrated in **Figure 5**. This new model outlines two possible trajectories for children later receiving an ASD diagnosis. Path *a* illustrates a child developing typically over the first one to one and a half years, whereafter a regressive pattern occurs meaning that some social or communicative skills are lost (Parr et al., 2011; Thompson et al., 2019). The other trajectory, path *b*, shows an early deviance from typical development, notable well before the child's first birthday. Note that none of the paths deviate at birth. This is not to say that genetic and biological factors might not be different from typical children early on–although imaging studies so far have been unsuccessful in identifying biological indicators of autism in infants below 6 months of age (see Shen and Piven, 2017). Instead, Model C suggests that any differences in social and communicative skills between children with autism and non-autistic children will not be easily detectable this early on a behavioral level. This proposal is in line with what we saw in the literature search, in which few studies reported a difference between children at risk

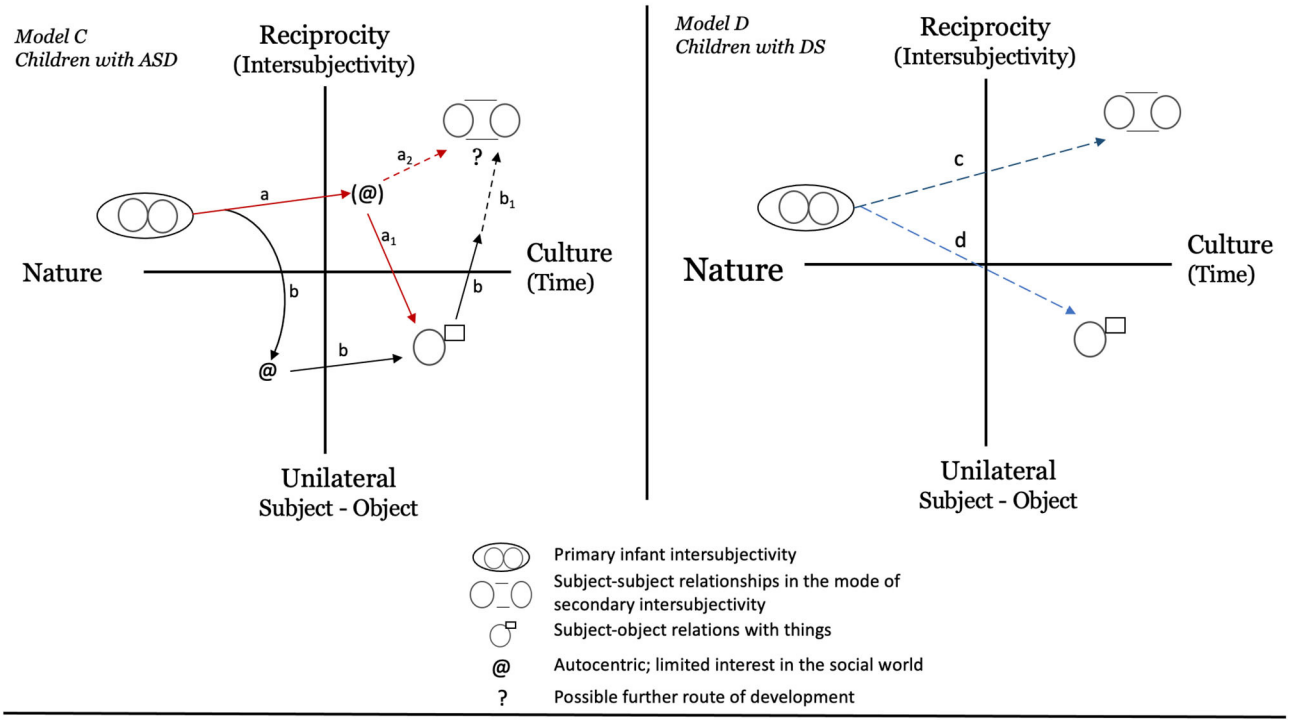

FIGURE 5 | Proposed new models based on the observations presented in the text. Model C represents ASD and Model D describes tentative paths for DS. *Explanations* of paths: *Model C:* (1) Path *a* depicts a child with autism developing along a typical trajectory over the first 12–18 months where after a halt in development takes place and the child loses social abilities previously mastered (indicated by path a_1). This child might eventually find a renewed social interest (maybe via an intervention) and move via path a_2 to develop a capacity for subject-subject relationships. (2) Path *b* depicts a child lagging behind in social ability already during the first year but note that even this child has the capacity for primary intersubjectivity at birth. The child might stay in a mindset that is occupied with subject-object relations but may also later move toward the social world (illustrated by b_1). *Model D:* Paths *c* and *d* are almost identical to the paths in the original model presented by Bråten (1996) for typically developing children. As in Model C, the infant has the ability to act in a complementary way and the participants step into each other's dialogic circle already from the start. The figure also illustrates different developmental paths for relations with people as compared to objects. The main difference from Bråten's original model is that instead of solid lines, the lines here are dashed in an attempt to illustrate that children with DS usually show a slower pace of development and might not reach the expected end state.

for ASD and typically developing children during the first year of life.

Berger (1990, p. 137) concludes that most "infants with DS are able to enter into reciprocal interactions with their parents soon after birth" even if some delay can be detected for early behaviors such as smiling, vocalizing, and eye contact. In Berger's sample, mutual eye contact displayed a delay of 2.5 weeks in onset. This is also reflected in Model D (**Figure 4**) that illustrates two main trajectories for how subject-subject (path *c)* and subject-object (path *d)* relationships might develop for children with DS. Note that these paths are similar to what we would expect for typical children (Dunst, 1990; Bråten, 1996; Heimann, 1998). The main difference being that children with DS usually show a much slower pace of development and might not reach the expected end state.

According to the findings presented here and in the Heimann et al. (1998) paper, it would, in our view, be wise to add imitation to the list of early social behaviors that children with DS might display. A capacity which signals that most children with DS have the capacity to establish relationships with the quality of primary intersubjectivity at birth or very shortly after. All children in the DS sample discussed here had at least a month of experience before they took part in the experiment. Thus, we cannot disentangle an innate capacity from rapid learning during their first month of life.

From a theoretical point of view, the observations provided suggest the possibility that both ASD and DS children are born with a mind that has an ability for primary intersubjectivity that makes it possible for them to enter into early dialogues as described by, among others, Reddy (2008). In this way, their starting state seems similar to what we expect to observe in typical neonates. This further implies that the difficulties we see later in development most probably are not caused by a lack of ability for rudimentary social interaction but, instead, emerge when the conditions for interaction changes, possibly when typical children start to engage in secondary intersubjectivity. Another possibility is that for children with ASD, the non-social world at some stage becomes more "attractive" than the social. As suggested by Davis and Crompton (2021), the evolving difficulties will, for some autistic children, also be influenced by non-optimal bidirectional processes that repeatedly create a mismatch between interacting partners, in this case within the

early parent-infant dialogues. This is not to say that autism is caused by caregivers' responses, only that also children on a path to autism is affected by continuous positive or negative social experiences.

There are some limitations to consider when interpreting the findings reported here. To start, the empirical base for drawing any conclusion varies between our three studies. The literature search rests on a comprehensive scan across three central and relevant databases that allow us to be more definite about the scarcity of studies investigating imitation in newborn and young children with ASD or DS. The empirical support for the existence of an actual capacity to imitate for children with ASD or DS is however much weaker, close to non-existent. For ASD, we have a single home video that is <1 min long and only the parents' reassurance that the situation was spontaneously filmed. According to the information the parents provided they had never tried to elicit imitation before the video was recorded. Furthermore, a further limitation is that the video only contains documentation of imitation of TP and no sequence when the father was passive that could have been used as comparison. However, the fact that no other responses than TP is produced by Marcus during the brief video adds to the quality of the observation.

For DS, we have taken a new look at already published observations on imitation. Although the data consists of a small number of children ($n = 5$), they represent all published observations on near neonatal imitation for this group to date, as shown by our literature review. It should however be noted that the DS infants responded differently to what we usually observe for typical infants. The participating DS infants produced a higher frequency of TP in comparison with data from studies on typical infants (Heimann et al., 1998). We do not know if this is a difference that is significant when it comes to the capacity to imitate, but it should remind us that the abilities of newborn children with DS might not be identical to typical infants.

Regarding the literature search, although we worked systematically we might have overseen relevant search terms or additional databases. Perhaps even more critical, we did not sweep the field for gray literature (e.g., unpublished dissertations, null findings in file drawers), and we might therefore have failed to include relevant literature. There is reason to believe that a publication bias might exist in the area of neonatal imitation since there is skepticism in the field whether the phenomenon exists (e.g., Oostenbroek et al., 2016). This, in combination with the general issues in conducting studies on atypical populations (e.g., small populations, large heterogeneity, medical complications), might lead to an unwillingness to include clinical groups like ASD or DS in studies on neonatal imitation. Consequently, this leads to an absence of such studies in published literature which, in our view, is very unfortunate since it hinders theoretical advancements. A recent meta-analysis did conclude that there is evidence to suggest that neonatal imitation exists (Davis et al., 2021), and therefore we believe that it is warranted to focus more on individuals from atypical populations as we continue to investigate it.

CONCLUSION

Our study highlights the lack of empirical support for the notion that neonates with ASD or DS do not have a capacity to imitate. Although resting on limited evidence, we believe that our observations instead tentatively point in the direction of an imitative capacity also for children that follows a developmental trajectory different from neurotypical children. Thus, all newborn children are probably ready for social encounters, and during their first interactions with another human being, they will use their capacity for primary intersubjectivity to establish reciprocity.

It is also striking that our literature search revealed so few studies on neonatal or early imitation in children with ASD or DS. For ASD, this is despite the fact that imitation in general and neonatal imitation specifically have been theoretically in focus for a long time. The lack of studies including infants or neonates with DS is also surprising since this is a group of children identified very early, often before birth. Thus, it ought to be possible for clinicians to gather larger samples systematically over time. This would give us a more solid ground from which to evaluate how children with DS are capable of imitation early in life. For ASD it is more difficult to study neonatal imitation directly, but one possibility could be to include imitation in the neonatal period in future studies on siblings to children with ASD.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because the Down syndrome data has been published earlier and the home video is not public material. However, the procedure for the literature review is available in a **Supplementary Materials**. Any requests regarding the Down syndrome data or the home video should be addressed to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by The Ethical Review Board, Göteborg University for the Down Syndrome children. For the ASD home video, the parents gave consent and approved the final text. This study was conducted according to the World Medical Association's ethical principles as outlined in the Helsinki declaration. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin, including consent for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

The study was conceived by MH. Data were collected and analyzed by MH and EH. The manuscript was written jointly by both authors.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2021.701795/full#supplementary-material

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Comparison of Japanese and Scottish Mother–Infant Intersubjectivity: Resonance of Timing, Anticipation, and Empathy During Feeding

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Feeding involves communication between mothers and infants and requires precise synchrony in a special triadic relationship with the food. It is deeply related to their intersubjectivity. This study compared the development of mother–infant intersubjectivity through interactional synchrony in feeding between 11 Japanese and 10 Scottish mother–infant dyads, observed at 6 and 9 months by video. Japanese mothers were more deliberate in feeding at an earlier age, whereas Scottish mothers were significantly more coercive than Japanese mothers at an earlier age. Japanese mothers brought the spoon to infants with a pause to adjust the timing of insertion to match their infants' readiness, whereas this pause was not observed in Scottish mothers. Isomorphic mouth opening between mothers and infants was observed. This empathic maternal display is an important element of intersubjectivity in infant feeding that differed between Scottish and Japanese mothers. Scottish mothers' mouth opening always followed their infants' mouth opening, but about half of Japanese mothers preceded their infants. Further, the mouths of Scottish infants and mothers opened almost at the same time as spoon insertion. In contrast, Japanese mothers' mouth opening did not co-occur with the insertion but was close to spoon arrival, a subtle but important difference that allows for greater infant autonomy. The time structure of Scottish mother-infant interactions was simpler and more predictable at 9 months than in Japan, where the structure was more variable, likely due to a stronger regulation by Scottish mothers. In conclusion, Scottish mother-infant intersubjectivity is characterized as more maternally reactive and mother-centered, whereas Japanese mother-infant intersubjectivity is characterized as more maternally empathetic and infant-centered. Cultural differences in intersubjectivity during feeding between Japan and Scotland are further discussed in relation to triadic relationships and parenting styles.

Keywords: intersubjectivity, interactional synchrony, Japan and Scotland, mother–infant relations, empathy in feeding, mouth opening

INTRODUCTION

Feeding is essential for infant survival and health, and weaning is a biologically significant framework for understanding the development of infant independence from the mother (Trivers, 1974; Negayama, 1996). Human infants gradually become autonomous feeders over the first years of life in terms of hand and tool use (Connolly and Dalgleish, 1989; Norimatsu, 1993; Kawahara, 2005), and food choices (Pliner, 1994; Tovar et al., 2016; Cole et al., 2018).

Mothers assist their children's feeding by providing food, cooking, and assisting with feeding when they are young and unable to manage it on their own (Wright, 1989). Such maternally supported infant feeding requires synchrony of intentions and actions on both sides, with attunement of these between mother and infant to ensure effective food intake, without choking. Interactional synchrony, or shared time, is fundamental to many domains of mother–infant intersubjectivity, and exists in the relationship even during the prenatal period – it is the basis of harmony between them (Feldman, 2003; Trevarthen et al., 2006). Infant feeding supported by the mother consists of a sequence of actions, or behavioral units, made with shared timing, and is one striking example of mother-infant intersubjectivity (Feldman, 2007).

Empathy and Mother-Infant Intersubjectivity

As they feed their young infants, some mothers show an interesting behavior of mouth movement (**Figure 1**) which is isomorphic with the infants' mouth movement (Negayama, 1993; Kawata, 2014; Toyama, 2014). The behavioral symmetry could be a demonstration of mother-infant intersubjectivity. The neurophysiological background of behavioral mirroring has recently been discussed (Meyza and Knapska, 2018), and mouth mirror neurons are found for ingestive behavior in non-human primates (Ferrari et al., 2003).

Co-occurrence of symmetrical mouth movements is a sign of empathy in the feeding mothers (Negayama, 1993), and complements infant-mother "sympathy" as directly feeling the other person's affective and intentional state (Trevarthen, 2016). It is supposed that orofacial communicative behavior has its evolutionary origin in the mother–infant dyad (Ferrari and Coudé, 2018). Non-verbal expressive actions of the body serve to mediate connectedness, and together with the mirror neuron system enables 'direct neural resonance,' a specific neural mechanism of shared affective and intentional neuromotor states that afford informed, intersubjective interactions with others (Gallese, 2009; Gallagher, 2012).

Human movements are never just functional and performative, but simultaneously express feeling in their kinematic form (Stern, 2010). These 'forms of vitality' convey an affective quality within the functional, performative aspects of movement that enrich intersubjectivity, sharing feelings in the intentional acts (Di Cesare et al., 2017; Di Cesare et al., 2020). And withholding expectation by pausing or coming in too quickly can raise arousal to generate excitement, or anxiety (Gratier, 2003).

This feeling is shared between individuals in their form and timing of body movement, made in the intersubjective 'dance' of their interaction (Malloch and Trevarthen, 2009a). Sharing feelings in sympathy, individuals may then reflect on these empathically to give "emotional and mental sensitivity to another's state" (de Waal and Preston, 2017). Where sympathy names feelings in direct resonance, empathy allows for additional reflection or mentalizing and "assessing the reasons for it and adopting the other's point of view." Sympathy allows the organism to quickly relate to the states of others, and effectively empathize with their experience. These are essential for the regulation of social interactions, coordinated activity, and cooperation toward shared goals (Clay et al., 2018). In this paper, we employ a mother-infant feeding paradigm as a lens with which to observe the nuance of the intersubjective relation between mother and infant. Mother-infant feeding requires shared timing and symmetry of behavior. It is a clear and accessible case of embodied mother-infant intersubjectivity, with the maternal empathetic mouth opening giving one sensitive behavioral index of it.

Differences in Mother–Infant Intersubjectivity by Infant's Age and Culture

Importantly, interactional synchrony is required between mothers and infants to attune and harmonize their behaviors for cooperative effect. The process of mother-infant feeding is a continuous adjustment of the timing of food giving (maternal) and intake (infant) actions. Empathetic mouth opening by the mothers to the infants' mouth opening at the moment of infant eating is a situation typical in everyday feeding of shared timing between the two.

The intentional nature of all human action, evident from before birth, underpins shared action understanding (Delafield-Butt and Gangopadhyay, 2013; Trevarthen and Delafield-Butt, 2017) generated within embodied, enactive interactions (Trevarthen and Delafield-Butt, 2013; Fantasia et al., 2014). Thus, motor timing in interaction shared between mother and infant presents an empirical measure of the shared intersubjective exchange. Set within shared projects, such as during infant pick-up or during feeding, these single acts become serially organized to give narrative structure, a narrative arc, as each act unfolds over time, altogether achieving the shared goal of the project (Trevarthen and Delafield-Butt, 2013; Rossmanith et al., 2014; Delafield-Butt and Trevarthen, 2015).

Empathy of feelings shared in sympathy cumulatively works over the whole process of feeding. Communication between feeders and infants with control, request, rejection, and cooperation between them (Stevenson et al., 1990; Negayama, 1993; Toyama, 2014; Fries et al., 2017; Nonaka and Stoffregen, 2020) reflects biological and cultural fundamentals of mother-infant relationships and their development.

Feeding induces a stronger empathetic mouth opening in mothers when providing food on their own than when just watching the infant being fed by the father (Negayama, 2000). This finding suggests that synchrony is not just reflection of behavior but could be boosted by the mothers' anticipation of

FIGURE 1 | A Japanese (top) and a Scottish (bottom) mothers showing an empathetic mouth movement (opening and closing) while her infant is taking food.

infants' food intake. Eating is a continuous narrative between mother and infant containing intention-reading and anticipation.

From as early as 2 months old, infants adapt their action to match imminent action intentions of their mother. For example, when being picked up from the floor, an infant will arch its back and raise its arms and stiffen in preparation for the new forces and requirements of being picked up (Reddy et al., 2013). The infant is prospectively aware of the imminent consequences of their mothers' actions, revealing an anticipatory awareness and self-generated adaptive, preparatory response to meet those expected demands. This basic action understanding is the embodied basis of understanding other minds (Trevarthen, 2001; Gallagher, 2012).

As demonstrated in Japanese mother-infant tickling play (Ishijima and Negayama, 2013), infants start to show joint attention with the mothers to a part of the infant's body at 6 months. This is "*proto-triadic* relationship" (Negayama, 2012, forthcoming) that precedes "*genuine triadic* relationship" at 9 months (Tomasello, 1995; Negayama, forthcoming). Feeding is an example of the triadic relationship between parent, infant and food. The development of this triadic relationship should be reflected in differences of behaviors and their timing.

Feeding is also an accessible, important paradigm to understand cultural differences in intersubjectivity in the mother–infant relationship. We are particularly interested in whether or not and how the mothers in Japan and Scotland differ in their empathetic mouth openings.

Previous studies have shown Japanese and Scottish mothers differ in distance regulation with their infants, and its manner (Negayama and Trevarthen, under review). Scottish mothers took greater initiative than Japanese mothers in this aspect. Japan–Scotland differences were also found in bedtime and sleep routines in both the home and day nurseries (Negayama, 1997; Negayama and Kawahara, 2010). Scottish mothers prefer putting children to bed without physical contact, whereas the Japanese mothers keep physical contact until their children fall asleep. The mothers and infants in Japan more often co-sleep at night, whereas those in the Western countries prefer to sleep separately (Caudill and Weinstein, 1969). These findings suggest a stronger empathy toward their children in Japanese mothers, and a preference for peaceful togetherness rather than their independence.

Interestingly, Japanese mothers often consume the food left by their infants, and give their own food to their infants when their infants' plates are empty ("cross-feeding," Negayama, 2006), which suggests they actively generate a sense of "oneness," a significant intimacy of shared, common experience in the dyad. This behavior is seldom observed in Scotland. Scottish mothers quickly withdraw from the role of feeder when their infants become autonomous in eating (Negayama, 2000). In contrast, Japanese infants refuse to be fed passively and do not establish independence in eating until later (Negayama, 1993). These examples suggest that Japanese mothers are more strongly guided by their empathy and motivation for shared experience with their infants.

On the other hand, if mothers prefer to direct and control their infants, then their infant's food intake would be regulated more strongly by their mothers. Conversely, if the mothers prefer to facilitate and share their infants' experience, then the infants would become more autonomous and the mothers will follow the infants. Thus, the present study sought to shed light on mother–infant intersubjectivity in feeding and its cultural differences in Japan and Scotland, by measuring the timing of their feeding interactions, especially over mouth openings of mothers and infants. It also could be postulated that cultural differences in mother–infant feeding relationships are expected to be evident over development, in this case between 6 and 9 months of age.

Purpose of the Present Study

Coordinated action timing and synchrony of feeding behaviors between mother and infant are for efficient feeding, matching the intentions of the mother and the infant. This matching is examined by recording the timing of the mouth openings of mother and infants during the feeds. Apparently 'synchronous' behaviors could be found to be asynchronous when examined in detail. For example, a mother may open her mouth earlier than her infant, or *vice versa*. Isomorphism of the two behaviors makes the minute analysis easy. The initiative for action in the intersubjectivity of mother-infant feeding can be examined by comparing the onset times of their mouth openings with micro-analysis of their occurrence. Alternatively, the mother's mouth opening might be regulated by some adjacent behaviors, for example, by the spoon's arrival (i.e., stagnation) at the infant's mouth, and insertion into it.

Fine micro-analysis of interaction timing during feeding serves as a promising window for exploring the age and cultural differences in mother–infant relationships. The basic question here is: Is the mother's empathetic mouth opening directly caused by the infant's mouth opening, or elicited by the mother's own intention? To answer this question, three behaviors of mother's empathetic mouth opening, infant mouth opening, and spoon carriage (particularly spoon arrival and insertion) are analyzed and compared. The analysis may demonstrate a variation by age and culture in the manner and style of more general mother–infant intersubjectivity, specifically analyzed here during feeding.

MATERIALS AND METHODS

Participants

Eleven Japanese (two boys and nine girls, five first-borns) and 10 healthy Scottish infants (five boys and five girls, seven first-borns) at the ages of 6 months participated with their mothers. They were recruited at local nursery schools by delivering an invitation letter in Japan and personally through word of mouth, parent groups, and nurseries in Scotland. Each mother and infant pair participated in the observation twice: first at the infants' age of ca. 6 months (*Age 1,* mean ages/SDs were 192.0/9.1 and 191.6/24.1 days in Japan and Scotland, respectively); and second at ca. 9 months (*Age 2,* mean ages/SDs were 282.2/16.2 and 289.8/16.7 days in Japan and Scotland, respectively). The other details of the participants are provided in Negayama et al. (2015). Participant numbers were limited and considered acceptable within the design due to the study requiring a precise time of laboratory-based recording within limited developmental periods.

This study was approved by the Ethical Committee of Waseda University (No. 2012-273) and the University of Strathclyde Ethics Committee. Written informed consent was obtained from each mother or father at the start of the study.

Procedure and Data Recording

The present study is a part of a larger research project carried out at *Ages 1* and *2*, in which (1) mothers put down then picked up their infants from the floor, (2) mothers fed their infant with solid food with a spoon, (3) mothers tickled their infant in free play for about 15 min, and (4) mothers and infants played an action-word game task. The first part (study of pick-up) has already been reported (Negayama et al., 2015).

Data recordings of Japanese and Scottish participants were carried out at a laboratory at Waseda University in Japan and another at the University of Strathclyde in Scotland. The entire process was recorded using two or more standard home video cameras with the assistance of a motion-capture system. The mothers were briefly interviewed after the experiment for background information on the infants (the birth date, family composition, parents' education and occupation, *etc.*). Written informed consent was obtained from each mother or father.

One Japanese case and one Scottish case were not observed at *Age 1* because solid feeding was not started yet. Feeding of 10 Japanese and 9 Scottish mother-infant dyads was filmed at *Age 1*, and of 11 Japanese and 10 Scottish dyads was filmed again at *Age 2*. Mothers brought solid foods from home to the laboratory and gave them to their infants with a spoon in their own way. The entire session was videotaped in each observation.

Behavioral Analysis

Feeding is a sequence of behaviors: food is scooped by a spoon and carried to an infant's mouth. The spoon stagnates before (or after in rare cases) reaching the infant's mouth (*arrival*), and is *inserted* (spoon tip passing the edge of the lips) into the infant's mouth. If the spoon does not stagnate, the time of arrival equals to the time of insertion. The infant *opens* the mouth at the moment of spoon insertion, but the mouth opening may be later than the insertion time. Some mothers *coerce* the infant to take the food provided by an exaggerated shooting movement toward the infant's mouth to elicit the infant's mouth opening. The spoon can be inserted and *pulled out* repeatedly until there is no food left on the spoon (*final withdrawal*), and then the spoon is *returned* to the initial position. *One spoon* refers to feeding from the start of the spoon carriage to the return. Simply the initial five consecutive spoon feeds were analyzed for these behaviors.

During feeding, mothers exhibit *empathetic mouth opening* (sometimes with chewing and closing), a fluid and reflexive behavior without reflective mentalization or strong volition. Another type of mouth opening also occurred which was to intentionally encourage the infant to take the food. This type quite often occurred with vocalization. In the present study, we focused on the former mouth movement, which was usually

silent, as a behavior indicative of the mother's intersubjectivity to the infant and ignored the latter one.

For a fine analysis of mother-infant interactions concerning the mother's empathetic mouth opening, a good video image of the mouth movements by the mothers and infants was needed. However, the initial five spoons were not appropriate for this analysis because the mother talked or the hand of the mother or infant hid their mouth. So, we selected as many as possible other episodes out of the entire feeding session for the analysis. the number of episodes collected by this way were 43 and 43 (range/median = 0–7/6 and 0–7/6) for Japanese *Age 1* and *Age 2*, respectively, and 50 and 52 (range/median = 3–5/5 and 3–9/4.5) for Scottish *Age 1* and *Age 2*, respectively.

The time sequence of the spoon-feeding episodes was measured using the video analysis software ELAN (Version 5.9.1) [Computer software] (2020), and then the time gaps of the behavior occurrences were calculated from the onset times of adjacent behaviors to determine the sequential relationship of the behaviors.

Because of the small numbers of samples and episodes, age and cultural comparisons were made on the basis of median values of the time for each dyad, and non-parametric tests were conducted for statistical analyses. Differences between the two age periods were examined by pairwise comparison by the Wilcoxon's rank-sum test, and differences between Japan and Scotland at each age were examined by Mann–Whitney *U* test. For both, the significance level was set at 0.05.

RESULTS

In order to substantiate intersubjectivity by a behavior, the timing and shape should be shared. Adjustment of mutual behaviors is needed for feeding, which is measured by timing of onset. The time structure of the behaviors, the synchrony of the mouth openings of the mothers and infants measured by the onset time are the focus of the analysis. Firstly, to understand the characteristics of the feeding interactions, a sequence of feeding was analyzed. The onset time and duration of each behavior were compared between the two stages (*Age 1* and *Age 2*) and between the two countries (Japan and Scotland) in general based on both the initial five feeding episodes and the additionally selected episodes. Then secondly, the mother's empathetic mouth opening was focused on, and the relationship of the timings of the behaviors of the mothers and infants were analyzed based on the additionally selected episodes.

Sequence of Feeding

One spoon carriage consisted of a series of different behavioral components (**Figure 2**): spoon departure from the starting point, spoon arrival near the infant's mouth, spoon insertion into the mouth, first spoon pulling-out, (repetition of insertion and pulling-out), final spoon withdrawal, and spoon return to the initial position. The infant's mouth opening to capture food occurs typically somewhere between spoon arrival and insertion. The relationships of the mother's empathetic mouth opening with the infant's mouth opening (Arrow A), spoon arrival (Arrow B), and spoon insertion (Arrow C) were focused on.

A sequence of spoon movements can be divided into seven sections by the onset times of those behavioral components. Ten intervals were identified for analysis as indicated by Intervals ① to ⑩ in **Figure 2**. The feeding sequence was normally composed of these sections, and a general time sequence of feeding was separately compared between the two age points and between the two countries on the basis of the lengths of the intervals in the initial five spoons (**Table 1**).

The mother's empathetic mouth movement was the focus of the present study, but in **Table 1**, the behavior did not show significant differences between ages in Japan and Scotland (Wilcoxon's rank-sum test) or between countries at *Age 1* as well as *Age 2* (Mann–Whitney *U* test) in any of the Intervals ① – ⑥. Statistical significance was found only in the Intervals ⑦ – ⑩, i.e., preceding and following behaviors sandwiching the interactions containing the mouth opening. Thus there were no age or cultural differences in the length of core interactions containing the mouth openings.

In Japan, spoon arrival time (calculated from the start of the spoon's movement toward the infant, Interval ⑨) and its insertion time (also calculated from the start of the spoon's movement toward the infant, Interval ⑩) were longer at *Age 1* than at *Age 2* (Wilcoxon's rank-sum test, p's < 0.05 and < 0.01, effect sizes = 0.66 and 0.82, $n = 10$, for ⑨ and ⑩, respectively). This means that Japanese mothers spent longer in the preparatory phase of feeding at *Age 1*. However, such an age difference was observed in Scotland only for spoon insertion (Wilcoxon's rank-sum test, p's = 0.86 and < 0.01, effect sizes = 0.06 and 0.89, $n = 9$, for ⑨ and ⑩, respectively).

The duration of spoon-in-the-mouth (calculated as the duration between insertion and first withdrawal, Interval ⑦) was also longer at *Age 1* than at *Age 2* in Japan (Wilcoxon's rank-sum test, $p < 0.01$, effect size = 0.85, $n = 10$), but not significantly different between ages in Scotland (Wilcoxon's rank-sum test, $p = 0.17$, effect size = 0.45, $n = 9$). This means that Japanese mothers gave their infants more time for food intake at *Age 1*. The total time from spoon insertion to withdrawal (i.e., final pulling out, Interval ⑧) was shorter at *Age 2* than at *Age 1* in both Japan and Scotland (Wilcoxon's rank-sum test, $p < 0.01$, effect size = 0.82, $n = 10$), suggesting a more efficient and cooperative food-taking behavior on the side of the infants and smoother, more in-step food-giving on the side of the mothers at *Age 2*.

The Japan–Scotland comparison shows a significantly longer duration of the time of spoon-in-the-mouth until its withdrawal at *Age 1* (calculated as the duration of the spoon in the mouth from insertion until the first spoon pulling-out, Interval ⑦, Mann–Whitney $U = 18$, $p < 0.05$, effect size = 0.51, $n = 19$), but not at *Age 2* in Japan. This indicates that Japanese mothers were more patient and appeared to wait for their young infants to take the food from the spoon when it was in the mouth than their Scottish counterparts with their 6-month-old infants. Conversely, a quicker carrying of a spoon (Interval ⑨) was found in Japan than in Scotland at 9 months of age (Mann–Whitney $U = 91$, $p = 0.01$, effect size = 0.55, $n = 21$), but not at the earlier age.

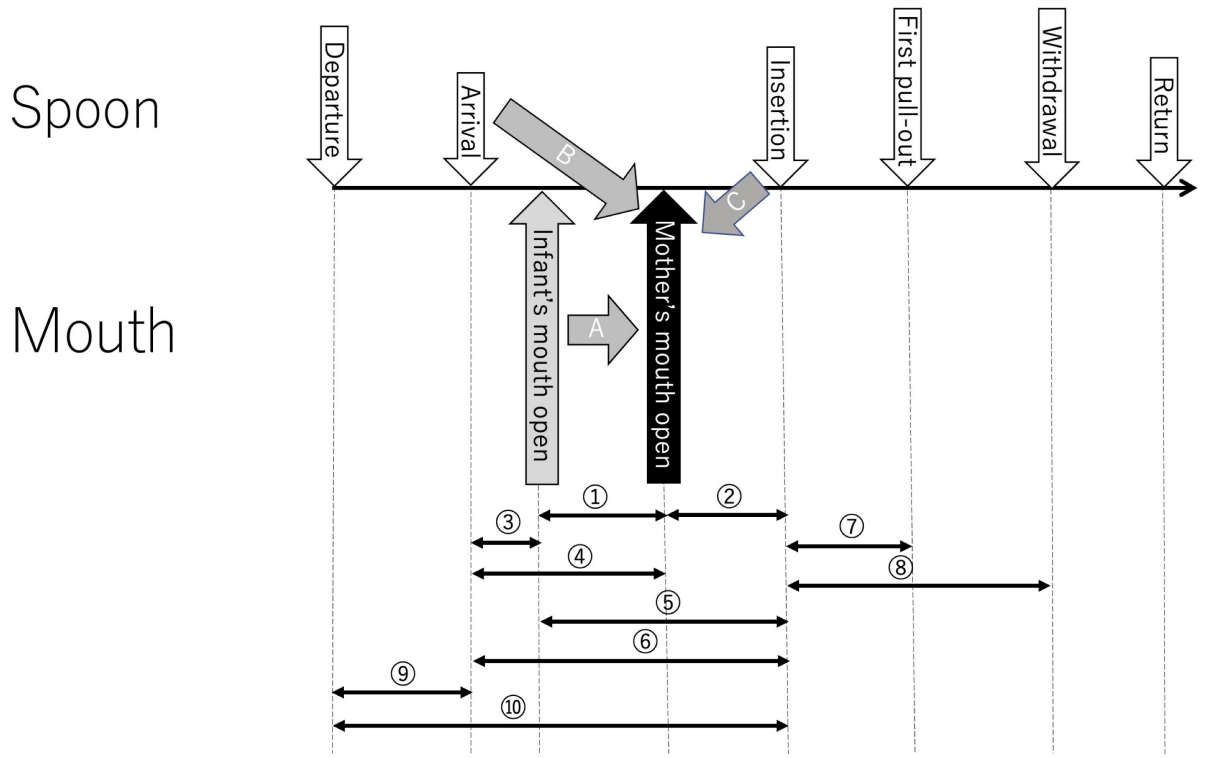

FIGURE 2 | The sequence of spoon-feeding segmented by the onset time of behaviors. The ten intervals denoted by circled numbers were selected for analysis. Arrows A, B, and C are assumed causal directions of the mother's empathetic mouth opening.

Despite their patience at the younger age, feeding times between Japanese mothers and infants became well-coordinated quickly.

Coercive behavior (**Figure 3**) was seen in some mothers during the movement of the spoon toward the infant's mouth (Interval ⑨). **Figure 4** shows the incidence of coercive feeding behavior in Japanese and Scottish mother-infant dyads at *Ages 1* and *2*. This behavior induced the infants to take the food, provided by an exaggerated shooting movement of the spoon approaching the infant's mouth. It was significantly more frequent in Scottish mother-infant dyads at *Age 1* (Fisher's exact test, $p < 0.01$), but not at *Age 2*. This appears to indicate greater initiative in feeding by Scottish mothers.

In contrast, Japanese mothers appeared inclined to adapt to the infants' initiative, waiting for an adequate time for their infants to take the food. The spoon was then kept in the infants' mouth for a significantly longer time in the Japanese dyads than in the Scottish ones at *Age 1* (**Table 1**). This suggests that the Japanese mothers have greater patience and a stronger infant-centeredness, allowing for and following their infants' initiative for food intake.

Relationship Between the Infants' Mouth Opening and Their Mothers' Empathetic Mouth Opening

The general analysis of the initial five spoons did not show any significant differences in the interactions relating with mothers' empathetic mouth movement. So the behavior was further analyzed in detail by deliberately selected video episodes in which the mothers' empathetic mouth opening was clearly observable.

This behavior might be induced by the infant's mouth opening (Arrow A in **Figure 2**), the mother's intention to insert the spoon into her infant's mouth at the spoon arrival might trigger it (Arrow B), or the mother's spoon insertion might evoke her mouth opening (Arrow C). Coupling the timing of the mother's mouth opening with that of the infant's and the spoon arrival/insertion gives a hint to understand the mechanism underlying the mother's empathy.

Figure 5 is a scatter plot of the differences of the onset times between the infants' mouth opening and that of the mothers' empathetic mouth openings (Interval ①; *y*-axis), along with the time interval from the spoon's arrival to the mother's mouth opening (Interval ④; *x*-axis) in Japan and Scotland. Data from *Age 1* (blue circles) and *Age 2* (red squares) are presented.

Time gaps between the Scottish infants' and mothers' mouth openings were more or less constant mostly within a 0–0.5 s range. The symbols were vertically plotted over zero for them, which means that the mothers quickly opened their mouths almost always later than the infants' mouth opening. In comparison, the symbols for Japanese mothers scattered more widely around zero, showing that the Japanese dyads were more flexible and variable in their interaction.

The regression line at *Age 1* is horizontal in Scotland, meaning that the Scottish mothers' mouth openings were a direct reaction

TABLE 1 | Comparison of median behavior intervals (sec) by country and age.

	From	To		Age	Country		Mann–Whitney
					Japan	Scotland	
⑨	Departure	Arrival		1	1.77	2.18	0.97
				2	1.44	1.99	**0.01***
			Wilcoxon		**0.037***	0.86	
⑩	Departure	Insertion		1	3.15	3.87	0.40
				2	1.69	2.37	0.13
			Wilcoxon		**0.009****	**0.008****	
⑧	Insertion	Withdrawal		1	4.09	3.07	0.28
				2	1.27	1.08	0.35
			Wilcoxon		**0.009****	**0.008****	
⑦	Insertion	Pull-out		1	3.82	1.09	**0.028***
				2	1.26	0.95	0.15
			Wilcoxon		**0.007****	0.17	
⑥	Arrival	Insertion		1	0.18	0.56	0.60
				2	0.45	0.02	0.56
			Wilcoxon		0.68	0.87	
③	Arrival	Infant's mouth open		1	0.09	0.27	0.50
				2	0.20	−0.06	0.47
			Wilcoxon		0.96	0.68	
⑤	Infant's mouth open	Insertion		1	0.32	0.24	0.66
				2	0.39	0.36	0.51
			Wilcoxon		0.39	0.31	
①	Infant's mouth open	Mother's mouth open		1	0.11	0.14	0.30
				2	0.35	0.37	0.74
			Wilcoxon		0.26	0.86	
④	Arrival	Mother's mouth open		1	0.01	0.58	0.05
				2	0.40	0.42	0.80
			Wilcoxon		0.14	0.44	
②	Mother's mouth open	Insertion		1	0.04	0.01	0.22
				2	0.11	0.15	1.00
			Wilcoxon		0.44	0.26	

*$p < 0.01$, *$p < 0.05$.
The bold means statistical significance.

to the infants' preceding mouth opening irrespective of the length of time after spoon arrival. This is related to the mothers' coerciveness in feeding. At *Age 2*, however, the time gap in Scotland decreased with the time after arrival. This reflects a change in the Scottish infants at *Age 2* to start opening their mouths even before the spoon arrival by reading their mothers' intention.

FIGURE 3 | Coercive behavior in a Scottish mother. The mother performs a shooting movement of the spoon toward her infant.

In contrast, some Japanese mothers opened their mouths earlier than their infants' mouth opening (the symbols plotted under zero). This means that Japanese mothers' mouth openings were not a direct reaction to their infants' behaviors, but were induced by the mother's own anticipation or intention. It is notable that the time elapsed from the infant's mouth opening to the mother's mouth opening increased along with the length of time from spoon arrival at both *Ages*, which suggests that the Japanese mothers' mouth opening was always linked with her own spoon carriage rather than evoked by the preceding infants' mouth opening.

Figure 6 compares the times of the infants' mouth opening (blue circles) and the mothers' mouth opening (red squares) after the moment of the spoon's arrival distributed along the time

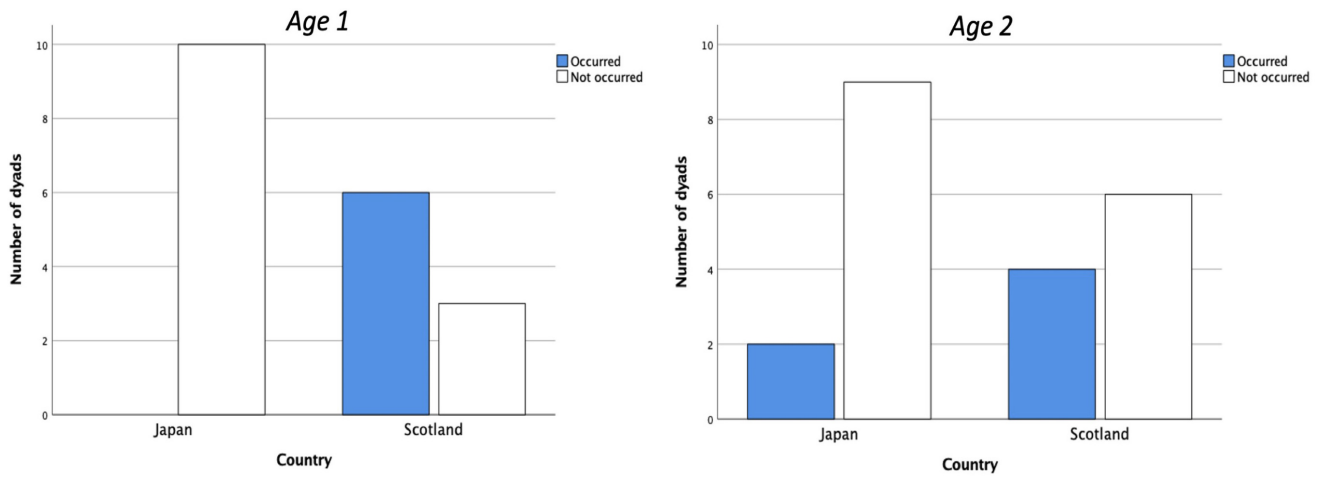

FIGURE 4 | Coercive feeding in Japanese and the Scottish mothers at *Age 1* (left) and *Age 2* (right). Fisher's exact test demonstrated significance between countries at *Age 1*, but not at *Age 2*. The differences in *Ages 1* and *2* are significant ($p < 0.01$) and not significant, respectively.

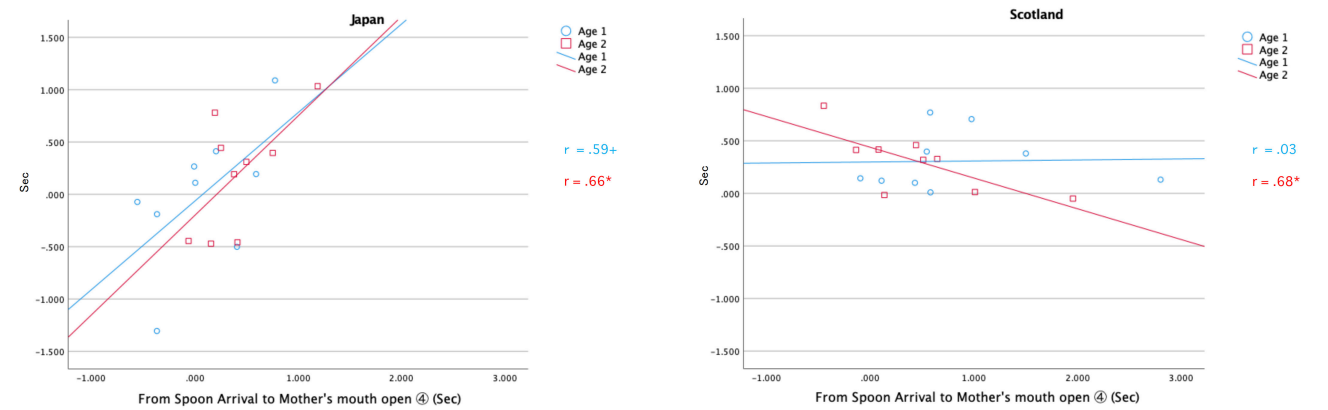

FIGURE 5 | Time differences (Sec) in the onset of the infant's mouth opening to that of mother's mouth opening (Interval ①; y-axis) along the time from spoon arrival to the mother's mouth opening (Interval ④; x-axis) at *Age 1* (blue) and *Age 2* (red) in Japan (left) and Scotland (right). $^{*}p < 0.05$, $^{+}p < 0.10$.

elapsed from the spoon arrival to its insertion. The dashed line indicates the time of spoon insertion after arrival. If the mouth openings of the mothers and infants were induced by spoon insertion, then the lines would parallel the dashed line. When the regression lines are below the dashed line, it means that the mouth opened before spoon insertion. But if the occurrence is coupled with spoon arrival, the regression lines should be horizontal, near the zero level.

Naturally, the infants' mouth opened near the time of spoon insertion, and the blue lines are almost parallel to the dashed line. The red lines are also parallel to and overlap the dashed line in Scotland, which means that the Scottish mothers showed perfect co-occurrence of spoon insertion and the infant's and mother's mouth openings.

On the other hand, Japanese mothers (red lines of the top two figures) showed a quite different tendency, i.e., being constantly horizontal at slightly above the zero level, which means that the Japanese mothers tended to open their mouths immediately following the spoon arrival irrespective of the time of the spoon insertion (proving Arrow B rather than A or C of **Figure 2**). In other words, the Japanese mothers apparently carried the spoon to the arrival point at just the right moment for the infants' food intake judged from their infants' state, and adjusted the spoon carriage to that state. The mothers stagnated the spoon and waited for the infant's mouth opening if the infants unexpectedly did not show it immediately. This appears to be a more infant-centered feeding style that observes and imagines their infants' state, anticipating their infant's food taking. The mother's mouth opening was thought to be caused by her empathetic motivation. In comparison, the Scottish mothers adapted the carriage of the spoon to the infants' condition *after* arrival. Together with their high incidence of coercive feeding, this suggests a more assertive feeding style that attempts to lead the infants. This suggests their mouth opening was a response to the infant's food-taking evoked by the mothers' coercive spoon carriage (Arrow A rather than B or C of **Figure 2**).

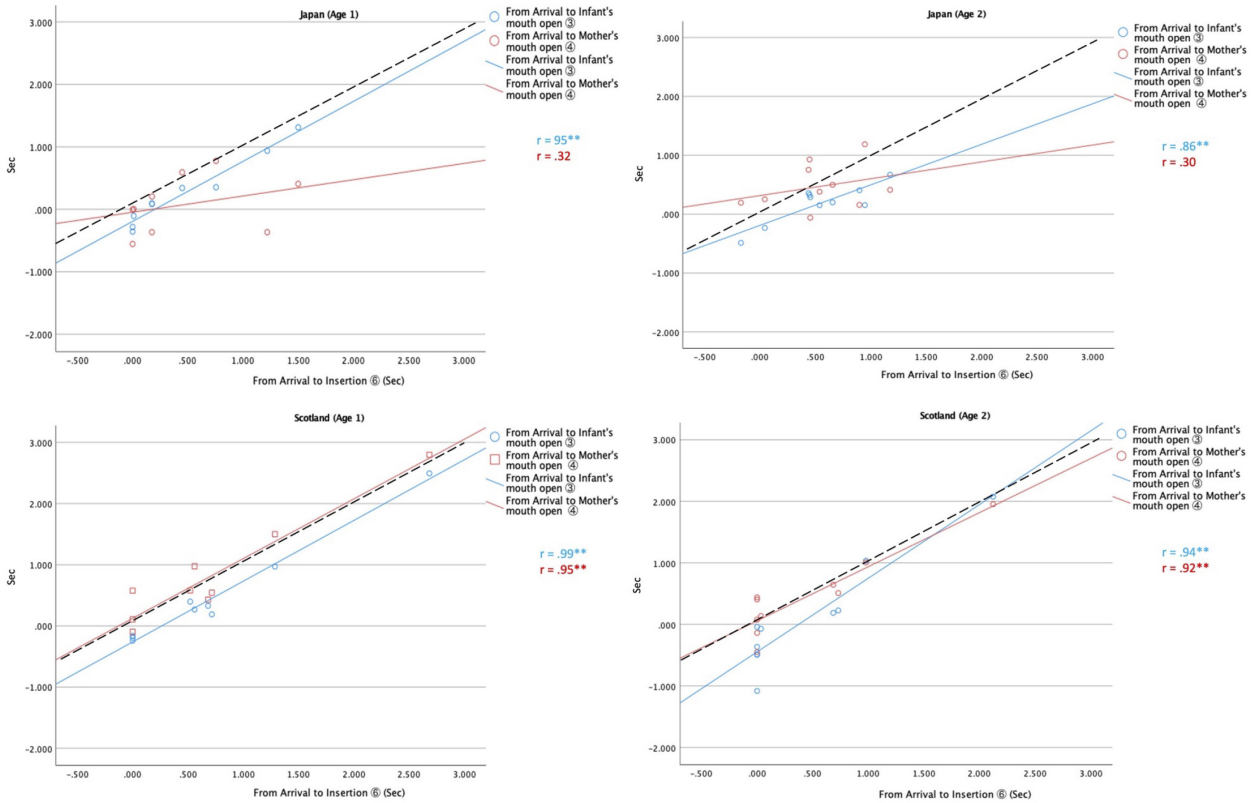

FIGURE 6 | Time (Sec) of the mouth opening by the infants (blue) and the mothers (red) after the spoon arrival (Intervals ③ and ④; *y*-axis) along the time elapsed after the spoon arrival to insertion (Interval ⑥; *x*-axis). The dashed line indicates the time of spoon insertion after arrival. $^{**}p < 0.01$.

The Scottish dyads were concentrated around the left-end zone of the horizontal axis. *That is,* little arrival-insertion gap, indicating that the spoon was pushed directly to the infant's mouth without preceding stagnation or adjustment. This tendency can be pointed out in Scotland at both *Ages 1* and *2*, but is particularly remarkable at 9 months of age. The symbols of Japanese dyads were more widely scattered because the mothers tended to be more deliberate in attuning to their infant's initiative before they initiated carriage of the spoon for feeding.

More constant reaction of the Scottish mothers to the infants' mouth opening with a short interval mentioned above suggests that their intersubjectivity was directly triggered by the infants' mouth opening. Intersubjectivity among the Japanese mothers, in contrast, appears to be based on empathy with the infants' intentions. In other words, the Japanese mothers' intersubjectivity was of a more anticipatory nature that followed their infant's initiative, and the Scottish mothers' intersubjectivity was of more directive.

The analyses above show the connection between the mouth openings of infants and mothers. To examine the regularity of the interactions containing the mouth openings of the mother and infants, the correlation matrix of Intervals ① to ⑥ at *Age 1* and *Age 2* by Spearman's rho are shown separately for Japanese and Scottish dyads in **Table 2**. Regularity demonstrated by high correlations between the intervals was thought as an evidence of structuredness of the feeding sequence, which made the mothers and infants to synchronize their mutual behaviors easier.

The most conspicuous result is the high ratio of significant correlations among the intervals at 9 months in Scotland. Particularly, there was an increase of significant correlations in the combinations with the infants' mouth opening in Scottish dyads compared to Japanese ones. This means that the time series of behaviors was more structured and therefore predictable in Scotland at *Age 2*.

We interpret this higher correlation as a result of reduced lability on the infant behavior due to the coercive maternal feeding style. This gave a compelling, structured interaction. Thus, the Scottish infants were unable to adjust their behaviors to this feeding style at *Age 1*, and later came to adjust their behavior to the mothers' feeding at *Age 2*.

In contrast, the Japanese mothers allowed greater freedom for their infants, which was possible by the more sensitively attuned feeding by the mothers that followed their infants and made the interaction more flexible. In Japan, the interactions became more complex, because the infants' spontaneity was prioritized and thereby interactions were more diverse. Thus the correlation of the Japanese dyads remained low at *Age 2*.

TABLE 2 | Correlations of length of intervals at *Age 1* (Top) and *Age 2* (Bottom).

Age 1		**From arrival to insertion ⑥**	**From arrival to infant's mouth open ③**	**From infant's mouth open to insertion ⑤**	**From infant's mouth open to mother's mouth open ①**	**From arrival to mother's mouth open ④**	**From mother's mouth open to insertion ②**
Japan	From arrival to insertion ⑥	1.000	**0.976****	−0.399	−0.276	0.494	0.059
	From arrival to infant's mouth open ③		1.000	−0.345	−0.383	0.417	0.133
	From infant's mouth open to insertion ⑤			1.000	0.267	−0.250	0.117
	From infant's mouth open to mother's mouth open ①				1.000	0.567	**−0.750***
	From arrival to mother's mouth open ④					1.000	**−0.783***
	From mother's mouth open to insertion ②						1.000
Scotland	From arrival to insertion ⑥	1.000	**0.831****	−0.051	−0.034	**0.695***	−0.186
	From arrival to infant's mouth open ③		1.000	−0.150	−0.367	**0.800****	0.017
	From infant's mouth open to insertion ⑤			1.000	0.017	−0.267	0.017
	From infant's mouth open to mother's mouth open ①				1.000	0.183	**−0.833****
	From arrival to mother's mouth open ④					1.000	−0.450
	From mother's mouth open to insertion ②						1.000
Age 2		**From arrival to insertion ⑥**	**From arrival to infant's mouth open ③**	**From infant's mouth open to insertion ⑤**	**From infant's mouth open to mother's mouth open ①**	**From arrival to mother's mouth open ④**	**From mother's mouth open to insertion ②**
Japan	From arrival to insertion ⑥	1.000	**0.655***	0.309	−0.455	0.224	0.564
	From arrival to infant's mouth open ③		1.000	−0.309	−0.624	0.115	0.527
	From infant's mouth open to insertion ⑤			1.000	0.188	0.345	−0.006
	From infant's mouth open to mother's mouth open ①				1.000	0.539	**−0.915****
	From arrival to mother's mouth open ④					1.000	−0.479
	From mother's mouth open to insertion ②						1.000
Scotland	From arrival to insertion ⑥	1.000	**0.899****	**−0.795****	**−0.860****	**0.847****	−0.317
	From arrival to infant's mouth open ③		1.000	**−0.879****	**−0.758***	**0.964****	−0.600
	From infant's mouth open to insertion ⑤			1.000	**0.806****	**−0.794****	0.345
	From infant's mouth open to mother's mouth open ①				1.000	**−0.648***	0.212
	From arrival to mother's mouth open ④					1.000	−0.564
	From mother's mouth open to insertion ②						1.000

***p < 0.01, *p < 0.05.*
The bold means statistical significance.

DISCUSSION

The results indicated that Japanese mothers were more attuned to their infants' states during feeding when the infants were at *Age 1*. In contrast, the Scottish mothers were more assertive in the spoon carriage with displays of coercive behavior with their 6-month-old infants. The mothers of both countries frequently opened their mouths when their infants' mouths opened to take food. The Scottish mothers' mouth openings occurred as a response to the infants' mouth opening by the spoon insertion, which itself was initiated by their more directive, mother-centered style of feeding. In contrast, Japanese mothers opened their mouths by empathic anticipation, encouraging their infants' food-taking behavior based on a more affective infant-centeredness.

Synchrony and Intersubjectivity

Temporal coordination in the mother-infant interaction during feeding is guaranteed by the infants' timely mouth opening at the moment of spoon insertion and the mothers' adjustment of their behavior to the infants' states.

The infants opened their mouths almost simultaneously but slightly earlier than the spoon insertion. This behavior was possible because of the infants' anticipation of the insertion, to which Tau Theory might be applicable for an explanation of the perception of gap-closure (Lee, 1976; Lee, 2009) operative in infant perception and action (Agyei et al., 2016; Delafield-Butt et al., 2018). This could be an underlying mechanism of the intersubjectivity between infants and mothers.

The infants responsively adjusted their mouth behavior to the mothers' spoon carriage. Mothers also carried the spoon at the right moment for coordinated action and common purpose with their infants, which requires the mother to perceive her infant's state of readiness, interest, and intention correctly. As the present study demonstrates, mothers open their mouths to their infants' food intake. This mother–infant symmetry of behaviors is strong evidence of their intersubjectivity. The mothers gave food to the infants, but simultaneously behave as if they were being fed as well, which shows shared feeling. Mothers' mouth opening occurred slightly later than the mouth opening of their infants, a feature more evident in Scotland.

Maternal experience of mother–infant intersubjectivity is different from, but deeply related to their infant's experience of that same intersubjectivity (Trevarthen, 2001). Food-providing by mothers is a uniquely human behavior, allowing the mothers' intersubjectivity and the infants' intersubjectivity to intersect in a clear and explicit manner in body movement and overt behavior. According to Trevarthen and Hubley (1978) and Trevarthen (1998), infants acquire secondary intersubjectivity at 9 months, characterized by a genuine triadic relationship (Tomasello, 1995; Negayama, forthcoming). The well-coordinated feeding of the Scottish mothers and infants at 9 months despite the mothers' coercive feeding at 6 months as well as the Japanese infants' quicker food taking at 9 months than at 6 months can be explained by the developing attunement of the 9-month-old infants to the shared object, the spoon.

Co-occurrence of the same mouth openings (mirroring) in mothers and infants is another unique characteristic of human feeding. The synchronous mouth opening by a feeder was also observed in an infant's father and a 2-year-old sibling at feeding infant (Negayama, 2006). Joint attention of the mother and the infant to an object in a triadic relationship requires taking the other's perspective (Tomasello et al., 1993). This allows for infant learning the particular mindedness of his or her mother. Learning such perspective-taking is embodied within the intersubjective engagement between the mother and infant.

Tickling play is another interaction between mother and infant with joint attention to a part of the infant's body, which similarly demonstrates this *proto-triadic* relationship evident at 6 months (Negayama, 2012). Feeding is another special, preliminary type of triadic relationship between mothers, infants, and food as a target. Food stimulates the infants' naso-oral sense organs, but it also arouses the mothers' taste and tactile naso-oral sensations. This is another dimension of mother-infant empathy, enriching the intersubjective triadic relationship with imagined expectations and real sensory experiences of taste, naso-oral sensations and sensorimotor tasks. And mother and infant ultimately share in the pleasure or displeasure in the accomplishment of the shared project (Delafield-Butt, 2018). This resonant relationship of intercorporeality can be understood as "embodied simulation" (Gallese, 2009), and the embodied triadic relationship is called a *quasi-triadic* relationship (Negayama, forthcoming; Negayama and Nakano, in press). Feeding shares the same basis of learning in co-created, co-operative projects that form the foundation of shared meaning-making invariant in human life (Trevarthen and Delafield-Butt, 2015; Delafield-Butt and Trevarthen, 2020).

Age and Cultural Differences

The Scottish mothers appeared more coercive and took the initiative to provide food at 6 months of age, and their infants followed them. Furthermore, their tendency to push a spoon into the infant's mouth without a preceding stagnation or adjustment sensitive to their infant's intention was observed. The Scottish mothers were more mother-centered, and the infants adjusted their behavior to their mothers. This means that the process was framed by the mothers' leadership, and the structure became simpler because of the infants' compliance.

In contrast, there was a greater flexibility in Japanese mothers, which was related to their long and deliberate spoon carriage by their infant-centeredness and cooperativeness. The Japanese mothers in the infant pick-up experiment of this study were also gentler and more deliberate with kneeling and had a slower approach before picking up the infants than the Scottish mothers, and the Scottish mothers were quicker in crouching to pick up the infants than the Japanese mothers (Negayama et al., 2015). Therefore, the Japanese mothers' intersubjectivity was framed by expectation of the infants' food-taking rather than mirroring of the infants' behavior.

The Japanese mothers' mouth opened with a constant length of time after arrival, irrespective of the time to insertion. In other words, the mothers started the carriage at an appropriate time for food intake and did not need to adjust the movement to

the infant state after departure, because the two were already aligned: the Japanese infants were more autonomous than the Scottish infants, and the Japanese mothers followed their infants and waited for the right time to bring the spoon of food for feeding by monitoring them.

It is also notable that some Japanese mothers opened their mouths earlier than the infants' mouth opening. These could be signs of anticipatory intersubjectivity among the Japanese dyads, and the infants would gradually learn the same psychological trait of intention-reading through the above-mentioned resonant experience between mother and infant at 6 months of age.

Such empathy-driven intersubjectivity is more likely to characterize Japanese dyads with infant-centeredness in their mothers. Japanese mothers' strong empathy was also pointed out when putting the infants to sleep with physical contact. This was to avoid a sadness or hardship on both sides by being left alone (Negayama, 1997), which could be related to '*Amae*' (Doi, 1992). In Scotland, on the other hand, the mothers' strong coerciveness during feeding played an important role in its shared timing or synchrony. This is similar with Scottish mothers' preference for isolated sleeping in a bed separate from their infants (Negayama, 2006, forthcoming). The Scottish mothers then mirrored their infants' mouth opening, generating a reactive intersubjectivity. At 9 months, i.e., the age of secondary intersubjectivity and genuine triadic relationship, however, the Scottish infants became to open their mouth before the spoon insertion by reading the mother's intention.

Intersubjectivity is the basis of coordination of feelings, intentions, and desires between bodies (Trevarthen, 2001). This coordination of movement and voice develops a shared project, or narrative, that allows for the development of interpersonal and cultural meaning (Gratier and Trevarthen, 2008; Malloch and Trevarthen, 2009b; Trevarthen and Delafield-Butt, 2013; Delafield-Butt and Trevarthen, 2015; Delafield-Butt, 2018). Mother-infant feeding timing and synchronization of mouth movements serve as indicators, or physical expressions of an embodied intersubjective resonance between them, serving to structure and organize the shared project. The different elements of timing, anticipation, and empathetic mirroring underpin the process. In this paper, we have identified differences in these psycho-motor structures that illustrate two different cultural types of intersubjectivity in Japan and Scotland, and suggested how these become culturally transmitted, and learned by the next generation.

Intentions are carried in movement, and the source of those intentions (empathetic or directive, as we have found here) becomes apparent in their shared experience. This allows learning of the particular maternal characteristics of mind-mindedness (Meins et al., 2002), and the transmission of a culture. Murray et al. (2018) postulate neurofunctional architecture which increases an occurrence of infant behavior when a caregiver mirrors the infant behavior. This functional architecture is a part of intersubjectivity of infants to respond in certain ways to specific forms of parental display (Murray et al., 2016). Bozicevic et al. (2021) demonstrate that cultural difference in maternal responsiveness mediate difference in the infant's later communicative behavior.

Two different types of parenting have been repeatedly pointed out in contexts other than feeding: control or regulator type and warmth or facilitator type (Raphael-Leff, 1993; Azuma, 1994; Bornstein, 2015). These studies show Japanese parenting can be classified as the latter type, relying more on affective ties and empathy than parental control. On the other hand, Western parenting can be relatively classified as the former type. Our present result follows this dichotomy, and the different characteristics of intersubjectivity in feeding between Japan and Scotland described here are embodied in it. Japanese mothers' lack of happiness and satisfaction in their motherhood compared to French and American mothers (Negayama et al., 2012) could be related to this limited autonomy in mothers.

Study Limitations and Future Work

First of all, this study is based on a small sample size, and the findings should hence be taken with caution despite an availability of other studies providing support for the current conclusion. Non-parametric tests applied to the small sample size have limited what we could determine. It should also be noted that this study took place in semi-naturalistic conditions within a public, laboratory setting in front of video and motion capture cameras. Although the mothers were instructed to behave normally, they were on stage in public, and this may have affected their intersubjective posture with their infants. The performance we observed may have been a publicly acceptable form of interaction that might have differed from that in private. Future studies will confirm these results with unobtrusive video. Recent advances in markerless motion capture technology for more naturalistic data collection could test for potential differences between public and private forms of intersubjective cooperation in feeding, and in other shared behaviors.

Further Perspectives

Eating is not just an activity where children take food to their mouths and swallow it. Instead, it is a cluster of behaviors related to parent-child relationships in a broader context. Feeding is a social activity involving both cooperation and antagonism between mothers and infants. Infants' desires about what, when, and how they eat do not always accord with the expectations of their mothers. Parents and infants sometimes conflict with each other and try to read each other's intentions and negotiate. The onset of refusal behavior by children in the transition from dependent to independent eating is a meaningful change (Negayama, 2011). This happens at about 9 months of age, the beginning of the genuine triadic relationship (Negayama, 1993).

Children trying to eat in the way they want and rejecting their parents' control frustrates their parents who want to feed them properly. The children read the parents' intentions and try to manipulate them. This is related to parents' pushy feeding or coercive control, showing the conflicting nature of eating as a situation of mutual manipulation by the parents and the children (Jansen et al., 2017).

Through such negotiation and co-regulation, children establish a parent-child centrifugalism, promoting independence from their parents. It is not a coincidence that these changes co-occur with the development of secondary intersubjectivity

at 9 months of age. Kawata (2014) explained this kind of children's protest for autonomy in eating as "psychological reactance" (Brehm and Brehm, 2013). Companionship between mother and infant develops on the basis of this co-regulation (Trevarthen, 2006).

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethical Committee of Waseda University (No. 2012-273) and the University of Strathclyde. Written informed consent to participate in this study was provided by the participants, in the case of adults, and the participants' legal guardian/next of kin, in the case of the infants. Written informed consent was obtained from the individual(s) and minor(s)' legal guardian/next of kin for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

KN contributed to the conception and design of the study, led data collection in Japan, and wrote the first draft of the manuscript. JD-B contributed to the design of the study, led data collection in Scotland, and co-authored and edited the manuscript. All authors contributed to methodology development and data collection. KN and KM performed the statistical analysis. All authors contributed to observation and manuscript revision, read, and approved the submitted version.

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Intersubjectivity: Conceptual Considerations in Meaning-Making With a Clinical Illustration

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This manuscript explores intersubjectivity through a conceptual construct for meaning-making that emphasizes three major interrelated elements–meaning making in interaction, making meaning with the body as well as the mind, and meaning making within an open dynamic system. These three elements are present in the literature on intersubjectivity with a wide range of terms used to describe various theoretical formulations. One objective of this manuscript is to illustrate how such a construct can be useful to understand the meaning-making observed in psychoanalysis, such as in the treatment of a young child on the autistic spectrum. The challenges in establishing an intersubjective state with a child on the autistic spectrum serve to highlight important features of intersubjectivity. As an important background to this clinical illustration, we illustrate the construct with the scientific paradigm of the well-known face-to-face still-face.

Keywords: intersubjectivity, human development, face-to-face still-face, autism spectrum disorder, dyadic states of consciousness

INTRODUCTION

We provide a conceptual construct of meaning making that emphasizes three interrelated elements—interactions with others, interactions through bodies as well as minds, and interactions in an open dynamic system–all of which have an established history in the literature on intersubjectivity. The concept of intersubjectivity inherently embraces the importance of interactions among individuals in the process of making meaning, just as there is a line of thinking that emphasizes humans making meaning with their bodies as well as through language. The formal characterization of meaning making as a dynamic systems process is of more recent vintage, although this important perspective also has a history in the literature. The usefulness of this multifaceted conceptual background on intersubjectivity can be illustrated by considering the experimental setting of the Still Face and then by considering a more complex clinical therapeutic setting.

As noted, our conceptualization is framed within the general principles of non-linear systems theory. In our use of intersubjectivity, the exchange of meanings between two individuals

is highlighted as potentially co-creating new meanings that are more complex and resource-enhancing than the meanings each individual had previously contributed to the exchange. This model fulfills Prigogene's first principle of open dynamic systems: Systems must gain resources – in our view meaning– to maintain and expand their organization. Failing that, they dissipate (Prigogine and Stengers, 1984).

This formulation also emphasizes that meaning making is most effective when occurring in interactions between two humans, in intersubjective experiences. That is because the meanings that are exchanged, and the potential co-created new meanings, are more complex than those made by an individual alone. Moreover, intersubjectivity is not the end state of the process. Rather, achieving intersubjective states generates a connection to the other, a trust in oneself and in the other, and a more coherent sense of self in relation to the world (Tronick and Gold, 2020).

This enhanced co-created meaning involves neurosomatic elements, by which we mean bodily elements that are often out of awareness, quite apart from the verbal elements. The multiple sources of meaning-making—of the conscious mind, the dynamic unconscious, the motor system, the endocrine system, the tactile sensory system, and others—create polymorphic forms of meaning that evolve over time and fit only messily together. One of the mysteries of the process is that from this constantly and messily evolving temporal flow of meanings, each individual assembles meanings that allow her to maintain a sense of continuity as a unique individual, a coherent sense of herself in the world (Sander, 2008).

MEANING MAKING IN INTERACTION

An important body of research emphasizing interactions among two individuals in meaning making has introduced various terms including Joint Shared Attention, Theory of Mind, and Interaction Theory. It is beyond the scope of this manuscript to consider all this large literature, but it is useful to provide some background on the various studies and nomenclature as a means of acknowledging this critical component of meaning making.

In the 1970's researchers described young infants' capacity to share the focus of attention with an adult when prompted by pointing or eye gazing (Scaife and Bruner, 1975). These observations stimulated questions about how infants come to be aware that other minds know theirs and that they can know another's mind. Bruner posed the question succinctly: "Is it so farfetched that humans know in some crude way from the start that their conspecifics have in common certain experiences of "inner states" like intending or desiring and that in time with the development of sufficient processing capacity they grow more "expert" in reading these experiences and states?" (Bruner, 1995, p. 3). Bruner clarifies his idea of joint visual attention as a "scaffold" for the later emergence of theory of mind. Bruner notes Tomasello's focus on the importance of the infant's recognition of intentionality as a critical feature of the scaffold (Tomasello, 1995). Even 1-year old children can distinguish between events that were physically caused, such as dropping something accidentally, or intentional (Poulin-Dubois and Schultz, 1988). Bruner elaborates his view of scaffolding in a 1978 manuscript describing the "active negotiation" in the dialog of a mother and child reading a picture book (Ninio and Bruner, 1978).

The concept of theory of mind was further developed in the false belief studies. Wimmer and Perner (1983) and Baron-Cohen et al. (1985) studied young children's ability to distinguish between beliefs based on reality and beliefs held in another person's mind in the Sally Anne or false belief test. In his studies of autism, Baron-Cohen (1995) described "mind blindness" as the inability of autistic individuals to imagine another's mental state. However, further study of the false belief test revealed that infants and toddlers do in fact demonstrate theory of mind skills when they are given tests appropriate to their developmental level. For example, Onishi and Baillargeon (2005) found that 15-month-old infants looked longer–indicating surprise—at a false belief situation than at a true belief situation involving a hidden toy, and Surian et al. (2007) obtained the same result in an experiment using an animated film about an animal searching for an object.

Tomasello et al. (2007) described how infants will use pointing to influence others' mental states. In support of Bruner's idea of scaffolding through social negotiation, O'Madagain and Tomasello (2021, p. 4077) describe a "uniquely human sociolinguistic phenomenon... "joint attention to mental content" through which children develop their rational capacities.

Two theories—theory theory (TT) and simulation theory (ST) both describe indirect processes that use either theoretical inference (TT) or simulation—putting oneself in the other person's position (ST)—to understand another person's mental state. Considering these theories, the infant researcher Reddy (2008) describes the impossibility of disembodiment in her description of how babies know minds and proposes a creative elaboration of intersubjectivity in infants.

A significant step forward (and going beyond TT and ST) was developed by Gallagher (2004, 2008) in his Interactive Theory of social cognition. Interactive Theory (sometimes referred to as enactive intersubjectivity) describes ways of achieving an interactive experience through bodily matching and interactive synchrony (Fuchs and De Jaegher, 2009; De Jaegher et al., 2010). This theory is reminiscent of Beebe's demonstrations of vocal coordination in the mother-infant dyad (Beebe and Lachmann, 2002; Beebe et al., 2005). Gallagher (2013, 2020) further elaborated Interaction Theory in his comprehensive Pattern Theory of Self, in which the self is conceptualized as constituted by multiple characteristics including bodily, experiential, affective, intersubjective and other features (Gallagher and Daly, 2018).

THE BODY AND INTERSUBJECTIVITY

We know that humans also make meaning about other human beings not only with their minds but also with their bodies, out of conscious awareness. In his seminal work, Merleau-Ponty (1945) introduced the term intercorporeality to underscore the

role of the body in meaning making. Merleau-Ponty elaborated the importance of the bodily experiences in developing pre-conscious understandings of the world and its meaning, a process that is open-ended and always changing (Tanaka, 2015). This process applies to all individuals, including children (Apter et al., 2019). Indeed, in infants and young children–given their lack of language and reflective awareness–Tronick (1980, 2007) has argued that intercorporeality is especially essential in meaning making.

Trevarthen (1974, 2005) was one of the first to describe the intersubjective meaning-making of infants and mothers with their bodies, noting that "even newborn infants. . . communicate intricately with the expressive forms and rhythms of interest and feeling displayed by other humans. . . (giving evidence of) purposeful intersubjectivity, or an initial psychosocial state" (Trevarthen and Aitken, 2001, p. 3). Trevarthen refers to the social intelligence of the infant as "a specific human talent—an inherent, intrinsic, psychobiological capacity that integrates perceptual information from many modalities to serve motive states" (ibid, p. 4).

Trevarthen also notes that the infant's responsiveness to the rhythms of his mother begins before birth—with the infant's perception of the mother's heartbeat, and the rhythms and tonalities of her speech and the speech of others in the environment. These perceptual capacities and the infant's active reciprocal responsiveness prepare him to meet his parents and to know them (Trevarthen and Delafield-Butt, 2013). All this occurs before language (DeCasper and Spence, 1986; Hepper, 1991; Fifer and Moon, 1995; Lacanuet and Schaal, 1996). Trevarthen describes how these capacities support the "emergence and development of active self and other awareness in infancy" (Trevarthen and Aitken, 2001, p. 3). In what he calls his descriptive research, Trevarthen (2015) elaborates the infant's bodily means of making meaning. He elaborates the infant's use of the body in intersubjective meaning-making through his work with Malloch, using the term communicative musicality to describe the coordination of time patterns through the body with the purposeful aim of the infant's movements (Malloch and Trevarthen, 2009).

Porges (2011, 2015, 2020) and Porges et al. (2014) has developed theories about the neural regulation of bodily organs and how they affect behavior and emotional responses in dyadic interaction. Porges (2004) uses the term neuroception to describe the non-conscious system for detecting threats to safety. An example of these neurosomatic processes is the meaning making of the kindling effect on brain neuronal activation that leads to making meaning of a non-threatening event as dangerous (Hofer, 2006; Haglund et al., 2007). Porges' concept of psychological safety that is communicated by bodily movements is critically important to the clinician.

In children, Snidman et al. (1995) has shown that infants who are shy or inhibited in contrast with uninhibited have different cardiac reactivity patterns to similar events. These cardiac differences are thought to underlie individual differences in behavior and differences in meaning made of the same event. For example, the inhibited children were fearful of a toy robot, whereas the uninhibited children readily played with it. Similar effects on meaning making are found for children in sensory integration clinical work with young children.

Research finds a variety of neurosomatic mechanisms underlying the differences in meaning made of events. Conradt et al. (2015) have shown that at 4 months of age children whose mothers were stressed during pregnancy have poorer attention during face-to-face play and poorer self-regulatory capacities when stressed during the Still-Face paradigm. They found that the behavior and the meaning of the event as more stressful was related to the methylation of the placental gene (NR3C1) that transforms maternal cortisol into cortisone, resulting in greater exposure of the developing fetus to neurotoxic effects of higher levels of cortisol. Thus, fetal experience affected how the infant made meaning of the event after birth.

Regarding intersubjectivity, studies have been done of meaning making with neurosomatic coordination of behavior and gestures (Hofer, 1984; Montirosso et al., 2012, 2014). Interestingly, some of these behaviors were related to sex differences in the infants (Tronick and Cohn, 1989; Weinberg et al., 1998). Tronick interpreted the sex difference as suggesting that girls are better able to modulate their reactivity than boys, producing a more benign meaning for the girls. Intersubjective neurosomatic coordination, or what Ham and Tronick (2009) call relational psychophysiology, is observed in cardiac and parasympathetic activity, and even in brain activation (Feldman et al., 2011; Konvalinka et al., 2011). Many other examples (see, Feldman, 2007; Montirosso et al., 2013, 2015; O'Brien et al., 2013; Tronick and Perry, 2015), substantiate the essential point that the meaning made of an event is related to and affected by underlying neurosomatic systems that are out of awareness–not symbolic or verbal or related in obvious ways to cognitive processes–and that these processes occur between individuals and affect their experience of each other (Van der Kolk, 2009).

STILL-FACE EXPERIMENT

The Face-to-Face Still-Face paradigm (FFSF; Tronick et al., 1978) is a protocol in which the infant is positioned in an infant seat facing the mother, and the mother is instructed to play with her infant for 2 mins, at which moment she receives a signal to assume an expressionless face. The "Still-Face" condition is maintained for a subsequent 2 mins, after which the mother receives a second signal to resume her original responsive behavior toward her baby. During the still-face episode, infants typically attempt to engage the still-face mother by smiling, gesturing, and vocalizing. When that fails, the infants become distressed and experience physiological arousal–may drool, choke, and spit up. They avert their gaze from the mother and even turn their head away or arch their backs, communicating with their behavior their state of dysregulation and their attempt to manage the relationship through disengagement. In the reunion phase of the protocol, the infants generally regain their positive affect and reengage with their mothers, but often they display at least an initial hesitancy about resuming the social engagement. This experiment has

been used to reliably assess infants' ability to regulate attentional and affective states, as well as qualities of the infant-caregiver relationship (Adamson and Frick, 2003; Mesman et al., 2009; Provenzi et al., 2016). What can the Still Face tell us about intersubjectivity? Infants and caregivers communicate their affect and intention through behavioral exchanges, using facial expression, gesture, and vocalization (Harrison, 2014). With these methods they create coordinated rhythms and other patterns of expression that constitute meanings about their relationship, and from which they also derive meanings about themselves. The mother may derive meanings about the quality of her mothering, about her experiences with her own mother, or other relational meanings about experiences with her infant. She will make meanings with her physiological response to her infant's behavior and his physical appearance and smell, for example, a stress response to his crying, relaxation when hunger cries stop as he begins to feed. Some of these meanings will be organized by language, such as her assessments of her mothering behavior and her infant's responses, and these may become conscious memories. Many others will be out of her awareness. The infant is also making meanings with his mind and his body—meanings such as, "I like doing this with my mother," or "I do not want to do this anymore; I need a break," or meanings about contented satiety or discomfort in his gut. The infant communicates these meanings to his mother with his behavior. The cluster of meanings in mother and in infant at any particular moment constitutes the state of consciousness (SOC) of each partner (Tronick and Beeghly, 2011). The infant demonstrates various SOC's in the Still-Face—from the enjoyment of playing in the first 2 mins, to the eagerness to engage followed by distress during the Still-Face, and finally to the pleasure at re-engagement in the reunion phase. But what about the hesitation many infants display at the mother's initiation of play after the Still-Face?

We think that this hesitation demonstrates the infant's effort to make meaning of the Still-Face experience. It is as if he is saying to himself, "What just happened? What was that all about? Can I trust this reunion?" We suggest that the Still-Face, among other things, demonstrates the interruption of intersubjectivity held by the infant and mother during the play episode before the signal for mother to become unresponsive. It may be that the mother and infant did not enjoy a relationship with a predominantly positive affective tone before they participated in the still-face experiment, but at least they shared meanings about a repertoire of relational patterns—generating SOC's—between them (Tronick, 2007). One of these patterns might have been, for example, that when mother is sad, the infant's smiles may cheer her up, and the infant sees her face relax. In the Still-Face, the infant may cycle through all the behaviors that belong to their way of reconnecting after a disruption, and none are successful (Banella and Tronick, 2019). Without her help, the infant cannot make meaning of the experience she just had with this vitally important person. Since these relational patterns in infant-caregiver relationships are associated with neurosomatic meanings to create complex SOC's, the infant is disrupted in multiple domains, making the infant's subjective experience even more powerful.

INTEGRATION INTO A CONCEPTUAL FORMULATION OF MEANING MAKING WITH APPLICATION TO PSYCHOANALYSIS

While studies in cognitive science refer to dynamic systems concepts such as continuous evolving meaning making, our formulation owes a major debt to the important studies of Louis Sander, and we root our theory in infant observation and clinical psychoanalysis (Harrison and Tronick, 2007; Sander, 2008; Harrison and Beebe, 2018). The clinical perspective underlying our theory emphasizes certain features of the interaction such as those of messiness, multiple meaning making, and agency.

Though clinicians' narratives of their sessions are markedly linear and coherent, the actual interactions between clinician and patient are messy, and because of the multiple meanings or partial meanings that are exchanged between analyst and patient, along with their timing and mode of expression, we cannot predict which will result in an emergent property of the system. In Sander's view of interactive meaning-making processes as in continual evolution, "a flow of a sequence, of recurrence of expectancy within the recurring exchanges", (Sander, 2012, p. 168) new meanings emerge that may or may not be instantiated, with resonant effects on other subsystems of the hierarchically organized larger dynamic system. In this sense, the uncoupling described in cognitive science by Fuchs and De Jaegher (2009, p. 471) is not so much a way of "not melting into each other" as it is a moment for each partner to actively claim agency, and a moment for each to incorporate a newly co-created meaning into the self. It is closer to Winnicott's paradox "the experience of being alone while someone else is present" (Winnicott, 1965, p. 30).

INNER WORLD OF THE SELF AND DYADIC STATES OF CONSCIOUSNESS

Our conceptual formulation provides a place for the private inner world of the self that is not interpretable from the individual's bodily actions. This inner world holds the complexity but also the continuity of the self that begins in infancy and endures through the lifetime of an individual. Sander presents the paradox between "the uniqueness of each newborn. . . and each individual's own particular pathway of development, and the minutiae of events within the flow of interaction between infant and caregiver" and we would add—between the individual and the environment (Sander, 2008, p. 167). The resolution of the paradox, Sander says, is in seeing the developmental process as an integration of "being together with" and "being distinct from" (Sander, 2008, p. 173). In this meaning making process, the emergent properties of the dynamic system of the individual within the larger system of the individual interacting with the world are selected to include new complexity but crucially to maintain the necessary coherence to ensure the continuity of the self.

Tronick's concept of dyadic state of consciousness (DSC) resembles an intersubjective state, although it is more inclusive than what is typically thought of as intersubjective experience (Tronick et al., 1998). A DSC may occur between individuals when they use behavior to exchange intentions, affects, states of mind, and cognitive meanings with each other. This interaction has the potential to co-create new meanings that in turn can then be appropriated by each individual into their own SOC, their private sense of self, their own inner worlds. Individuals overcome the limitation of self-organizing meaning-making by engaging in dyadic meaning-making, in that way creating intersubjectivity. When an individual's SOC gains complexity and coherence, the individual undergoes an amplification of self-experience, a sense of emotional and cognitive expansion. Typically, this is pleasurable, but not always.

One might consider that psychoanalysis supports developmental growth through an evolving process of creating a DSC between patient and analyst, which then gets disrupted before continuing on to the creation of the next DSC (Harrison and Tronick, 2011; Tronick and Beeghly, 2011; Harrison and Beebe, 2018; Heller et al., 2019). The potential for creating DSC's through intersubjectivity is greater in psychoanalysis than in a typical relationship because of the explicit knowledge and experience of the psychoanalyst, the implicit relational knowing of both psychoanalyst and patient, the motivation and capacities of the patient, and the frequency of the sessions—offering many opportunities to make meaning together. However, in contrast with most psychoanalytic thinking, our view of intersubjectivity includes meaning-making with bodily and out of awareness neurosomatic meanings. As we have noted, neurosomatic meanings are made by polymorphic systems operating at multiple levels in the individual. These polymorphic systems of meaning-making include bodily movements to set points of physiological systems, and even genetics and epigenetics, as well as verbal and symbolic communications.

PSYCHOANALYSIS AND INTERSUBJECTIVITY

Psychoanalysis has embraced the concept of intersubjectivity as a way of explaining how one person gains access to another person's inner world. Led by the Relational School of Psychoanalysis, psychoanalysts have increasingly appreciated the importance of the concept of intersubjectivity, shifting the focus of attention from the inner world of the individual to include the relational matrix (Stolorow et al., 1994; Dunn, 1995; Seligman, 2018). Many see the intersubjective perspective—the idea that the focus of psychoanalysis is the interplay between two subjectivities—as having moved into the foreground of psychoanalytic theory (Stern, 2005; Benjamin, 2013). The literature on intersubjectivity in psychoanalysis is substantial and beyond the scope of this manuscript. We will instead focus on the polymorphic, or polysemic—capable of having multiple meanings–features of intersubjectivity as we use it in psychoanalysis, which extends the intersubjective perspective to include the body and mind of the individual in interaction with the body and mind of the other without disregarding the interaction of the individual with his or her own self, and while always preserving the integrity of the meanings made at each level.

Although psychoanalysis has increasingly introduced ideas about non-verbal communication into psychoanalytic theory, the means of achieving intersubjectivity remains primarily through the exchange of verbal meanings. With few exceptions (Beebe and Lachmann, 2002; Knoblauch, 2005; Harrison, 2014; Harrison and Beebe, 2018; Seligman, 2018), analysts typically describe intersubjective experiences as the verbal trading of evocative images and metaphors in combination with astute self-reflection—again, in thoughts organized by language.

We see the features of dynamic systems theory are particularly helpful to the practicing psychoanalyst in her work. She must contain the complexity of multiple evolving meanings that occur during the course of a clinical session. She must tolerate the uncertainty and variability of her patient's communications and similarly of her reactions to them. If she settles too quickly on a meaning, she may foreclose alternative meanings that are often represented at the same moment or in the flow of ongoing moments in a complex gesture. For example, an autistic child who expressed positive interest in the analyst but who also perceived her presence as a threat, moved to pick up a toy near where she was sitting, while also averting his gaze and turning his head and torso away. As she waited for the child to initiate another behavioral cue, accepting her not knowing position, the analyst communicated to the child her willingness to give him a turn, to support his agency.

INFLUENCE OF AUTISM ON THE PROCESS OF MEANING MAKING

Individuals on the autistic spectrum disorder (ASD) have difficulty processing social stimuli, making presuppositions about how other people think and feel, and therefore, creating intersubjective meanings. Baron-Cohen's false belief studies were motivated by an interest in learning about autism. Baron-Cohen et al. (2001) have more recently shown that factors other than those attributable to ToM may be involved in these difficulties. For example, a significant relevant finding is that ASD individuals have difficulty recognizing vocal cues (Chevallier et al., 2011; Porges et al., 2014). Another important finding is ASD individuals' diminished social interest (Dawson et al., 1998). It seems logical that if autistic individuals neglect social cues in infancy, their progressive neurodevelopment takes on a different form of organization–one we do not understand, but one that does not support typical social and intersubjective capacity. Social perceptual skills developing during childhood and linked with social cognition, scaffold social skill—or ToM skill–development (Schultz, 2005).

Another theory from cognitive science relating interpersonal problems in autism to intersubjectivity is that the development of Trevarthen's primary intersubjectivity in ASD individuals is compromised by a basic impairment in the sensory-motor capabilities that young children use to make sense of their

connection with others before language (Trevarthen, 2005; Trevarthen and Delafield-Butt, 2013). This basic impairment in bodily interaction with the environment also leads to a central problem of integrating perceptual experience, or a lack of central coherence (Gallagher, 2004). An example of this lack of capacity to integrate perception with context is when a gifted autistic child who learned to read at 2-years old, looked at a picture of the cardinal directions on a new toy with arrows and N, S, E, and W arranged around a circle and said, "That says 'news'."

BACKGROUND ON THE CLINICAL ILLUSTRATION

Clinical insights into intersubjective processes can be gained through the treatment of the highly heterogeneous group of ASD individuals because of their atypical processing of sensory perceptions, bodily experience. In a clinical vignette of an ASD child, we will illustrate how intersubjective meaning was made between the child and the analyst through implicit awareness of bodily movements, rhythmic coordination, and (what we assume to be) perceptions of internal organs that we include within "neurosomatic" meanings–in concurrence with verbal meaning. Following Trevarthen (2005, 2009, 2015), we emphasize the centrality of the body in our concept of meaning making.

Though we do not have data on all the neurosomatic processes making meaning in this clinical case, the literature documents atypical neurosomatic reactivity of ASD individuals, for example, oxytocin (functioning as anxiolytic) release (Hammock et al., 2012), response to human facial expressions (Nelson, 2012), and the sounds of the human voice (Porges et al., 2014; Porges, 2019). From this evidence we can assume that the child described below makes neurosomatic meaning of his encounter with the analyst in atypical ways. The correspondingly atypical and creative behavioral communications described in the example demonstrate the multiplicity of meanings—the polysemic meaning making–taking part in intersubjective process more strikingly than if language and symbols alone were considered. In this examples, bodily movements used both explicitly and implicitly to make and convey meaning in the relationship illustrate how meaning making evolves in the analytic session. It is not possible, but if it were, we would also explore the neurosomatic processes involved, such as the autonomic and neurohormonal systems.

Our understanding of the behavioral communications in videotape is enhanced by the NCAST scales of infant behavioral cues. These cues, categorized into engagement cues and disengagement cues, have been validated by extensive observations of infant-parent dyads and used in many studies (Farel et al., 1991; Kelly and Barnard, 2000; White-Trout et al., 2013; see also P. Ogden on adult engagement cues, Ogden and Fisher, 2015). The engagement and disengagement cues, while serving as the primary communicators of affect and intention in infancy, persist in later life, although they recede in prominence as language becomes dominant. Behavioral cues are bidirectional, in that each individual in the dyad communicates affect and intention to the other in a back and forth or circular manner. Actually, they could be called double bidirectional in that simultaneously, each individual's behavioral cues are communicated to his or her own neurosensory system. If the infant communicates engagement to the mother with an open mouth and direct gaze, the mother will typically reciprocate with direct gaze and a smile, her softened facial expression and her gaze not only communicating the desire and intention of engagement to her baby, but also stimulate her own vagal system to generate a flexible sinus rhythm and a feeling of sociability (Porges, 2015). Porges (2015) describes the process of "neuroception" in which the goals and motivations of both inanimate and animate objects are interpreted out of awareness, sending signals to the temporal cortex, creating meanings of threat and safety. In our example, we will elaborate our descriptions by identifying some of the visible NCAST cues.

BACKGROUND ON THE PATIENT AND THE ANALYSIS

The clinical example is that of "Hal", a 3-year-old boy. Dr. A, the analyst, saw him in analytic play sessions four times a week. The session reported here occurred 6 months into the analysis. Dr. A videotaped the sessions and micro analyzed selected sessions, using a modified version of the technique developed by Beebe, in which the second-by-second vocal turns and "action turns" are documented using the Quick Time framework (Harrison and Beebe, 2018). The second-by-second description is reminiscent of Trevarthen's descriptions of an infant conducting a lullaby or of an infant shaping his mouth and tongue blowing bubbles (Trevarthen, 2005).

Hal had precocious language development, but his speech had the unmelodious quality of ASD individuals. He was interested in his peers but lacked the capacity for reciprocal play and had no real friends in his preschool class. When he had a plan in mind and was unable to accomplish it, he could become agitated and inconsolable. Hal was a gifted child and had an intense interest in–and competence in—reading maps. Dr. A understood this interest as a way Hal made sense of his world in two dimensions.

INTERACTIONS IN THE BEGINNING OF THE CLINICAL SESSION

In the session, Hal had the idea of creating maps out of "H-links", a construction toy. Dr. A had no idea how they would do this, but she joined in his plan with a feeling of pleasant anticipation. The following is what transpires at the beginning of the clinical session.

The segment begins with Dr. A placing the bin of "H-links" on the floor of the playroom. Hal then begins to organize the pieces. Dr. A walks around to a clear space next to Hal and in the first 6 s of the film, settles to the floor. At that moment Hal is gazing down at the H-links and has his back to her. Both his averted gaze and his bodily turn away are NCAST disengagement cues that communicate to Dr. A and to Hal himself his lack of readiness for

engagement. Hal does not acknowledge Dr. A's presence verbally or with his gaze.

At this point, Dr. A moves her hand to her chin. This gesture is a disengagement cue, communicating to Hal and to herself that she should hold back. At second 8, she removes her hand from her chin, looks down, and begins slowly to assemble a small pile of H-links near her. This activity—her activity with the toy but averted gaze–represents a conscious effort on Dr. A's part to connect with Hal at a distance, in other words, without direct engagement. At second 10, Hal appears to notice an H-link near Dr. A, and moves toward her, communicating an intention to engage (reach in the direction of Dr. A) but again, at a distance (averted gaze). At second 11, Dr. A extends her right leg as if to balance herself. At second 15, Hal brings back the H-link to where he was originally working, and as he leans to the right, Dr. A also moves to the right, continuing her slow, repetitive activity.

At this moment, Dr. A and Hal assume parallel body positions, leaning in the same direction with the same arch of their bodies, and with gaze down. Less than 1 s later, Hal speaks for the first time. He says, "These H-links don't go together that much."

ILLUSTRATION OF CO-CREATED MEANING MAKING IN THIS CLINICAL EXAMPLE

As Dr. A initially sits down next to Hal, it appears that Hal is not consciously attending to Dr. A's body movements, and he does not signal an acknowledgment of her approach. The message from Hal is 'My attention is focused on this toy, and information from the social world is not in my conscious awareness." Dr. A notices Hal's lack of acknowledgment and settles into a comfortable position. Consciously, she wants to respect Hal's agenda and prepares herself to wait until Hal initiates an interaction. However, she also makes an unconscious gesture, touching her hand to her chin, in an NCAST behavioral cue of disengagement. This unconscious gesture appears to indicate Dr. A's assessment of Hal's lack of preparedness for engagement and is a communication both to Hal and to herself, indicating, "I will not intrude." While the meaning of the communication relates to both of them, Dr. A is aware that Hal is not looking at her. This is a moment in an intersubjective process in which Dr. A is attempting to hold Hal in her mind but is also responding to him with her body. Some of the multiple domains of meaning making here are Hal's bodily activity indicating unreadiness, Dr. A's bodily sensory processing of Hal's movements and her own, and Dr. A's conscious mental activity.

In the next few seconds, Dr. A consciously chooses an alternative way of being with Hal rather than direct engagement. She generates with her own body a rhythm that approximates his small repetitive movements, in that way creating for herself a subjective sense of connection with him. Again, although she understands that he is not looking at her, she has the sense of communicating to him her readiness to engage but also her patience. When Hal moves toward Dr. A, he again appears not to notice her body positioned so closely to him in space, and Dr. A moves away slightly to accommodate his proximity, throwing herself slightly off balance and causing her to extend her leg to stabilize her position. Dr. A's gesture adds more complexity of meaning. Dr. A has the intention to join with Hal, but she inhibits her initiative because of her awareness of his fragility—how easily he can be disturbed by unanticipated physical closeness. As she becomes aware of his fragility, she creates—with her own bodily instability—a fragility within herself. This is also perhaps an intersubjective moment.

Consciously, Dr. A has the impression that Hal does not have her in mind at all at this point, while in his approach his body seems to be moving toward a connection. Two seconds later, Hal moves away again, and Dr. A and Hal assume symmetrical positions. It is as if their bodies are moving in relation to each other without making conscious or even dynamically unconscious meaning until they randomly achieve a "match" in symmetrical bodily positions at a distance. It is significant that the position is a "match" in the shape of their bodies but not in their gaze. This back and forth movement outside of conscious awareness resembles descriptions of interactions of component parts of a dynamic non-linear system, and one might call their sudden "match" in body positions an emergent property of their dyadic system. The emergent property is a way of being together at a distance and without conscious acknowledgment.

COMMENTARY ON THE CLINICAL EXAMPLE

This example illustrates the usefulness of the construct of meaning making as a non-linear "messy" process involving bodily as well as verbal interactions between a patient and a therapist, a construct that is not an element of standard psychoanalytic theory (Harrison, 2003, 2014; Harrison and Beebe, 2018). In this context, Dr. A and Hal are communicating a somewhat muted affect—mildly positive but tentative. Dr. A's intention is to make a connection with Hal, as is Hal's in a general sense, although it is not clear he has that intention at that moment. Also, although Hal is aware of how challenging it is for him to engage with another person, the meaning he makes of this difficulty is not entirely clear to Dr. A. Most likely, Hal sees the difficulty as originating from outside of himself—"this person is too close and I really don't like that—something bad is happening to me!"

A more complex formulation of meaning making allows us to put all these meanings, or partial meanings or meanings in evolution, together into a messy dynamic activity between two individuals. The non-linear framework means that we can be comfortable with not knowing what will emerge from this process.

It is likely that Dr. A and Hal will continue to make a connection because they meet together multiple times a week and have a fondness for each other. Yet exactly when and how they will make that connection is not at all clear from the interaction in this example. The non-linear systems theory allows us to accommodate the unpredictability and variability of this moment-to-moment attempt to create intersubjectivity. The "match" Dr. A and Hal make with their bodies assuming

symmetrical positions seems comfortable to Hal, and with neither verbal nor visual confirmation, Hal perceives a kind of engagement and initiates verbal communication for the first time.

It is also significant that the verbal communication Hal makes is a symbolic confirmation of the atypical characteristics of their match and the difficulty they have making it: "These H-links don't go together that much." Dr. A and Hal now have co-created a shared meaning in words and symbols as well as with their bodies. Though Dr. A thought she was not in Hal's mind until that moment, something about the interactive process of their bodies moving–perceiving the movement of their own and the other's bodies moving in space, in relation to each other–allowed them to co-create that shared meaning.

It is also a paradoxical meaning in that they are together with their bodies and yet not with their minds until Hal makes the statement of "these H links don't go together," at which point Dr. A takes in the complex meaning of their being together and can acknowledge the truth of what he says. Again, the reference to general principles of dynamic systems theory is helpful in that we can see the intersubjective experience gain in complexity and coherence through the emergent property of the building of connection in multiple domains of meaning making.

CONCLUDING REMARKS

The process of meaning making can be seen as an evolving process of multiple meaning-making activities, simultaneously occurring between two individuals and within each individual. Intersubjectivity, then, can be seen as related to each individual's state of consciousness, made up of many different meanings one is making of the self, including those in and out of awareness and of the body as well as of the mind, emerging from an active engagement with another's state of consciousness to create a dyadic state of consciousness.

This interplay could be elaborated to consider the interplay or potential messiness of the meanings between individuals, the polysemic discord of meanings within the individual, and the potential dynamic conflicts engendered in the within and between or the inter- and intra-subjective meanings. Each individual receives the dyadic states of consciousness as a subjective experience of enhancement, much as psychoanalysts describe intersubjective states. The dyadic state of consciousness contributes meaning to each individual's state of consciousness, but the subjective sense of enhancement does not last, because in the evolving intersubjective process each individual will exercise his or her own agency and the match with the other will be attenuated, until over time another dyadic state of consciousness is created. This process is similar to the moment of meeting described in Sander (2008). In this context, intersubjectivity describes the way humans grow in relationships, from the infant-caregiver relationship to all the other relationships throughout the lifetime.

The clinical example of Dr. A and Hal illustrates meaning making as a dynamic evolving and multifaceted process following a non-linear model that includes interactions between the analyst and the patient. The example also illustrates that the interactions involve bodily as well as verbal processes. The co-creativity is illustrated in the clinical example by Dr. A's bringing her hand to her chin after having settled her body to the floor next to Hal. The deceptively simple gesture is meaningful in many ways. First, it is a visual cue to Hal that she intends to back off or slow down. In this case, Hal is not looking at her, but it is clear that he is extremely sensitive to the movements of her body, so this meaning may have nonetheless been communicated. Second, with this gesture, Dr. A is out of her awareness reminding herself to back off or slow down. Consciously, she is thinking about being careful not to intrude into the space around him that Hal needs to feel safe; she knows both from her experience with Hal and her experience with other ASD children, that anxiety about social engagement can be triggered by even a slight physical intrusion. This latter meaning may be called Dr. A's implicit relational knowing about working with ASD children (Boston Change Process Study Group, 2002, 2005; Tronick, 2007). Finally, Dr. A's physical gesture of touching her face is self-regulating, calming her and relaxing her muscles of facial expression, which will send vagal messages to decrease her heart rate and rate of respiration (Porges, 2015). In the case of Hal, his gaze aversion and the lack of orientation of his body toward Dr. A communicates both to Dr. A and to himself his unreadiness to engage with Dr. A. Yet over time as Dr. A and Hal 's second by second gestures continue, they come closer together in the rhythms and positions of their movements. And Hal's astute comment that "these H-links don't go together that much" confirms in words their difficulty "going together" and indicates that he has been working hard on preparing himself for a connection, providing the promise of future meaning making between the two of them, albeit one that is dynamic and uncertain.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

AUTHOR CONTRIBUTIONS

Both authors listed have made a substantial, direct, and intellectual contribution to the work, and approved it for publication.

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Dialogic Book-Sharing as a Privileged Intersubjective Space

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Parental reading to young children is well-established as being positively associated with child cognitive development, particularly their language development. Research indicates that a particular, "intersubjective," form of using books with children, "Dialogic Book-sharing" (DBS), is especially beneficial to infants and pre-school aged children, particularly when using picture books. The work on DBS to date has paid little attention to the theoretical and empirical underpinnings of the approach. Here, we address the question of what processes taking place during DBS confer benefits to child development, and why these processes are beneficial. In a novel integration of evidence, ranging from non-human primate communication through iconic gestures and pointing, archaeological data on Pre-hominid and early human art, to experimental and naturalistic studies of infant attention, cognitive processing, and language, we argue that DBS entails core characteristics that make it a privileged intersubjective space for the promotion of child cognitive and language development. This analysis, together with the findings of DBS intervention studies, provides a powerful intellectual basis for the wide-scale promotion of DBS, especially in disadvantaged populations.

Keywords: intersubjectivity, dialogic book-sharing, infant attention, joint attention, language learning, pointing, gaze, parent-infant interaction

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INTRODUCTION

Disparities in children's literacy and educational achievements are of global public concern (Walker et al., 2011; Garcia and Weiss, 2017). Their roots are evident early in development, with substantial differences in language skills associated with family socio-economic status and parent education apparent by just 24 months (Fernald et al., 2013; Justice et al., 2020). Such early differences in infant cognitive functioning persist (Bornstein, 2014) and influence the life trajectory, including future education and employment (Fagan et al., 2007).

Educational disadvantage is transmitted across generations, with poor outcomes largely explained by aspects of the home environment (Sylva, 2014; Sammons et al., 2015). One important aspect is early parental reading to the child (e.g., Bus et al., 1995; Demir-Lira et al., 2019; Leech et al., 2022), a practice that varies widely between families (Logan et al., 2019). Indeed, a notable U.S. intergenerational longitudinal study showed that the strong association between parents' education achievement and that of their offspring when aged 29 years was accounted for by how much the parents had read to their child before they started school (Gottfried et al., 2015). Given such evidence, there have been efforts to promote parental reading

by providing families with books from birth through the early years [e.g., Reach out and Read (Zuckerman, 2009), Bookstart (https://bookstart.org.uk), Book Dash (www.bookdash.org), Mikhulu Trust (www.mikhulutrust.org)].

Aside from the simple amount of book-reading parents do with their children, *how* books are used is important. In particular, "dialogic" reading, or dialogic book-sharing (DBS), appears especially advantageous to children's language and literacy skills (e.g., Whitehurst et al., 1988; Bus et al., 1995; Hargrave and Sénéchal, 2000). This practice, which is very different from simply reading a book to a child who passively listens (Peskin and Astington, 2004), also varies across families, being less common in those that are more disadvantaged (Bus et al., 1995; Fletcher and Reese, 2005).

THE INTERSUBJECTIVE CHARACTERISTICS OF DBS

Young children's learning is fundamentally dyadic (Vygotsky, 1978). From the first weeks, infants engage in rich "primary intersubjective" face-to-face communication with their carers (Trevarthen, 1979), followed by a "secondary intersubjective" phase around 9-10 months characterized by shared attention to common referents (Trevarthen and Hubley, 1978; Tronick et al., 1979; Abney et al., 2020). Sharing picture-books typically starts in this latter phase, and is an intersubjective process in which books are used to support the child's interest and engage them in a reciprocal interaction. Book-sharing provides a contained space for joint attention in a physically close intimate setting that is associated with the secure attachment (Bus and van IJzendoorn, 1995, 1997) and shared physiological and affectively positive states (Waters et al., 2017) that promote cognitive and language development (Van IJzendoorn et al., 1995). Core characteristics of DBS are that the adult pays attention to what the child is interested in, follows their interest, and builds upon this in an emotionally supportive way that actively involves the child. Aside from gazing at and pointing to what the child is looking at and naming it, adult DBS behaviors include asking questions and pitching comments according to the child's developmental capacity (Vygotsky, 1978), linking the book content to the child's own experience, and supporting their interest through use of animated vocalizations and gestural enactment (Whitehurst et al., 1988; Cooper et al., 2014; Vally et al., 2015; see **Figure 1**).

Given the benefits of DBS, a number of programmes for training carers in this method have been developed. A recent meta-analysis of 19 randomized controlled trials of DBS training, including in highly disadvantaged communities, reported a large effect on caregiver book-sharing quality (mean $d = 1.01$); and, regarding child outcomes, it showed benefits to both expressive and receptive language, across the age range (12–60 months) (mean $d = 0.41$ and 0.26, respectively) (Dowdall et al., 2020). There is also evidence for a benefit of training parents in DBS on infant focal attention (Cooper et al., 2014; Vally et al., 2015), an important component of general cognitive processing (Smith, 2013) and a key predictor of scholastic functioning (McClelland et al., 2013). Importantly, intervention studies have shown that it is by virtue of the improvements in parent-infant book-sharing interactions effected by training that the benefits to child language and attention are brought about (Murray et al., 2016).

FIGURE 1 | Typical affectionate intersubjective behaviors in Dialogic Book-sharing, illustrated from the authors' training materials: **(A)** Following child gaze; **(B)** Following child pointing; **(C)** Pointing to focus of child interest and naming-elaborating; **(D)** Linking book-content to child experience and animating.

Here, we present speculation and evidence from independent research that may explain why DBS, particularly when using text-free or text-light picture books, is such an effective, or privileged, mode of supporting early development. First, we consider the possible evolutionary precursors and ontogenetic development of the capacity to harness picture-book images in the service of sharing meanings with others. We then focus on specific intersubjective, joint attention-relevant behaviors that are prominent in DBS, and consider their role in the development of child cognitive functioning. Finally, we note the linguistic characteristics of DBS.

THE PRIVILEGED NATURE OF BOOK-SHARING

Evolutionary and Developmental Precursors of Iconic Understanding

The development of shared understanding through iconic forms appears to have a long evolutionary history, and this could be a powerful driver of the capacity of infants and young children to apprehend the spatial arrangement of marks on a surface, as in picture books, to share reference to objects, individuals, or events in the real world. Thus, studies in the wild of the gestures used by non-human primates show that, despite the potential for numerous hand and limb configurations, there is a common repertoire of gestures across widely dispersed

species and populations, each one carrying similar meaning (Corballis, 2010; Hobaiter et al., 2014; Byrne et al., 2017; Graham et al., 2018). Notably, these gestures are characterized by their "iconic" spatial configuration as the limb is moved through space. Research also shows apes can be trained to use iconic symbols, deploying them flexibly in exchanges with humans (Bohn et al., 2016). With regard to early hominid use of iconic communication, deliberate markings on surfaces were used even by pre-Homo sapiens, as shown in Neanderthal cave art in the form of a hand stencil (minimum age 66.7 ka) and a scalariform sign (minimum age 64.8 ka) in Maltravieso (Hoffmann et al., 2018). In early Homo sapiens history, 43.9 ka, in Indonesia, in what is the oldest-known parietal art by modern humans, pictorial "narratives" depict what seems to be a communal hunt, with human-like figures using spears and/or ropes to flush animals from their cover toward waiting hunters (Aubert et al., 2019). This scene, regarded as the earliest evidence of communication of a narrative in Paleolithic art, is particularly notable because the invention of fictional stories may have been the last and most critical stage in the evolutionary history of human language and the development of modern cognition (Mithen, 2009; Boyd, 2018; Aubert et al., 2019).

Ontological Development of the Apprehension of Iconic Forms

The strikingly rapid ontological development of the ability to connect 2D images to their referents, possibly drawing on the pre- and early human evolution of iconic communication, has been well-charted in experimental research. For example, infants can recognize their mother's photograph by just 3 months (Barrera and Maurer, 1981), can use a picture to identify a specific object by 15 months (Preissler and Bloom, 2008; Ganea et al., 2009) and a generic object by 15–17 months (Geraghty et al., 2014); and by 18–24 months they can use just sparse visual information to recognize well-known objects (Smith, 2009). Remarkably, by the same age, infants can use a verbal label previously paired with a line drawing of an unknown object to select the referent object, in preference, even, to the familiar line drawing itself (Preissler and Carey, 2004). Finally, by 3 years, children are able to accept abstract line drawings as reflecting the drawer's intended referent, even when the drawing shows little, if any, physical resemblance to the object (Smith, 2003, 2013; Hartley and Allen, 2014). Concerning the apprehension of actions, although infants can infer intentionality from observation of abstract symbols in motion (Biro et al., 2007; Pomiechowska and Csibra, 2017), evidence is lacking concerning *static* arrays. Nevertheless, studies of adults indicate that only minimal two dimensional marks on a surface are required to detect intentionality, perhaps supported by a neural action observation network (AON) (Umiltà et al., 2012). Such activity may reflect a motor simulation mechanism, whereby the observation of deliberate marks produced by another person produces a first-person embodied experience. The fact that the relevant AON appears operational in infancy for manual gestures and facial expressions (Rayson et al., 2017; Debnath et al., 2019), make it plausible that the ability to apprehend intentionality, and possibly other mental states (e.g., basic emotions), from two dimensional depictions in picture books is in place by late infancy. This is particularly likely where the picture content is well-organized, and uses prototypical cues to depict the various categories of familiar objects, actions and emotions (see **Figure 2**).

Joint Attention in Book-Sharing

Joint attention in general is associated with a wide range of positive effects, both cognitive (Shteynberg, 2018) and emotional (Schilbach et al., 2010; Wolf et al., 2016). Establishing and maintaining a state of joint attention between adult and child is fundamental to good book-sharing, and below we consider specific aspects of joint attention that are prominent in this context.

Gaze Following

As noted, a key feature of DBS is the parent following their infant or young child's direction of interest. Experimental research across the age range has demonstrated the beneficial effects of having one's gaze followed for core aspects of emotional and cognitive functioning. Thus, evidence suggests that there is an expectation that our own gaze will be followed, with distinct motivational consequences when this occurs. Awareness that our gaze has been followed takes place very quickly, in less than half a second (Phillips et al., 2022), and even this brief time is experienced as compressed, via a "temporal, or intentional, binding effect" (David et al., 2008). Relatedly, when another person's gaze-shift occurs rapidly after our own, we sense it as being *connected* to our own gaze, and this leads to a positive, implicit sense of our agency (Pfeiffer et al., 2012; Haggard, 2017; Stephenson et al., 2018). Cognitive processing of the target of our gaze is also improved when our gaze to it is followed, vs. following another person's gaze, an effect that is evident from early infancy. For example, when a 6.5-month-old infant's own gaze to an object is followed, vs. being cued, by another's gaze, they show enhanced neural processing, as reflected in increased EEG-recorded alpha mu suppression (Rayson et al., 2019); and, under the same conditions, 10–12-month-olds show behavioral indices of efficiency of information processing (gaze-shift speed) and object preference (Ishikawa et al., 2019).

Consistent with experimental findings, naturalistic studies show enhanced infant attention and neural processing (alpha suppression) of objects during joint play, vs. solo play or simple observation (Wass S. et al., 2018; Meyer et al., 2022). Moreover, during joint play, when the parent visually attends to the infant's object of interest, infants extend the duration of their visual attention to the object, particularly if the parent's interest is sustained (Yu and Smith, 2016). Such effects seem to be mediated by the *nature* of the adult's attention to the infant: dual EEG measurement with 12-month-old infants and their parents showed that parents' theta power closely tracked and responded

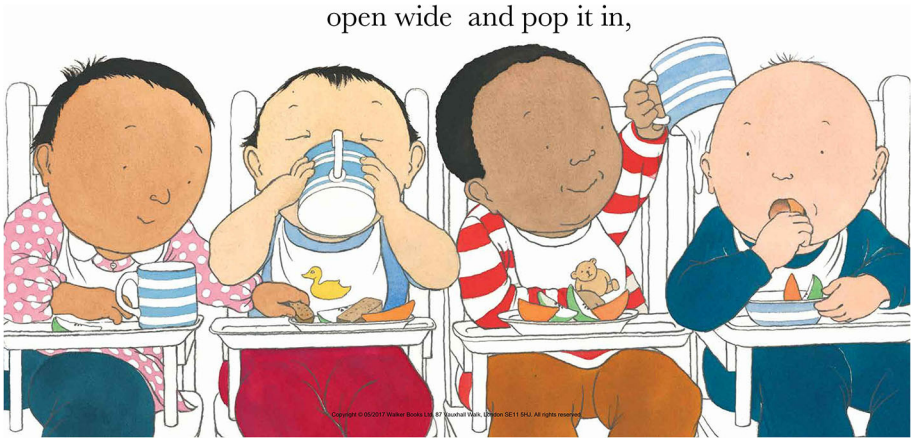

FIGURE 2 | This beautiful illustration by Oxenbury (1987) provides clear, repeated prototypical depictions of familiar categories of subjects, objects and actions whose reference can be readily apprehended by infants from around 1 year. It also presents parents with excellent opportunities for different levels of verbal scaffolding, according to their infant's age and experience. These can range from providing simple labels for the youngest infants ("baby," "cup," "drinking"), to linking to the infant's own experience and elaborating (look, that baby's got a cup like yours'), to talking about perspectives and mental states for older infants and children (Does this baby know that his biscuit's being taken? How does that baby feel when the other baby pours milk on his head?!). Copyright © 1987 Helen Oxenbury From CLAP HANDS by Helen Oxenbury Reproduced by permission of Walker Books Ltd, London, SE11 5HJ www.walker.co.uk.

to changes in their infants' gaze direction, and instances where parents showed increased neural responsivity were associated with longer periods of infant sustained attention (Wass S. V. et al., 2018).

Pointing

Around 9–12 months, infants come to understand pointing as object-directed, and their own pointing is related to their understanding of this property of others' points (Woodward and Guajardo, 2002). Developing this capacity might profit particularly well from the book-sharing context with its potential for sustained periods of joint attention to a series of targets. Indeed, pointing to the elements of picture book displays is a common feature of book-sharing behavior on the part of both infants and parents. Recent experimental studies have shown that, as for gaze following, significant benefits accrue from experiences involving pointing (e.g., Salo et al., 2019). Thus, at the neural level, when a target has attracted 8-month-old infants' attention, larger amplitude P400 ERP components are observed if the target location is then cued with a point (Gredeback et al., 2010). Benefits are also apparent when it is the infant who performs the point: even "solo" pointing can help infants' attention processing (Smith, 2013), though they typically point when others are available to respond (Begus and Southgate, 2012); and having their own pointing followed is associated with subsequent gains in vocabulary (Brooks and Meltzoff, 2008) and better learning (as indexed by imitation) of others' novel object-directed actions (Begus et al., 2014). Such benefits, like those of having one's gaze followed, may, in part, accrue from "action-oriented predictive processing" effects, whereby one's motor intentions elicit predictions about the results of our actions (Clark, 2013), with the subsequent, anticipated, events then evoking increased neural responsiveness (Engel et al., 2001). These mechanisms, largely studied under experimental conditions, could potentially occur in natural social interactions (de Hamilton, 2021; Monroy C. et al., 2021), including in book-sharing, such that infant attentional and gestural behaviors entailing anticipation and prediction of parental responses then elicit greater neural activation when those responses occur (Southgate et al., 2009; Monroy C. D. et al., 2019; Phillips et al., 2022).

Naming and Animating

Although an adult simply pointing to a target can influence infant attention (Butterworth, 2004), its effects when used in isolation from other behaviors may be limited. In fact, parental pointing during spontaneous parent-infant interactions is often part of a more complex display, including during book-sharing. Indeed, pointing combined with "naming" occurs more commonly in book-sharing than in any other conversational context (Dunn and Wooding, 1977), and is regarded as key to book-sharing's function as a "language acquisition device" (Ninio and Bruner, 1978; Ninio, 1983). Although basic associative processes may contribute to the word-learning afforded by pointing plus naming, the occurrence of this behavior during book-sharing is typically more dynamic than a simple temporal coincidence of auditory and deictic stimuli (Meyer et al., 2011). Thus, parents often use intonational and facial modulation for emphasis as they name the target of their pointing (Nencheva et al., 2021), as well as synchronized gestural animation (Novack and Goldin-Meadow, 2017), particularly when naming depicted actions. As such, the book-sharing context typically provides infants with highly enriched inter-sensory information.

Studies of infant attention to actual as opposed to depicted objects, and of word-object learning, confirm the value of the sort of "inter-sensory redundancy" (Gogate et al., 2001) that occurs in book-sharing. For example, within the first year, effects on infant attention of having objects pointed to are enhanced by the addition of vocal communication (Daum et al., 2013), and better learning of object-sounds/proto-word associations occurs when their presentations are synchronized (Gogate and Bahrick, 1998), or the object dynamics suggest animation or deixis (e.g., "looming"; Matatyaho-Bullaro et al., 2014). Further, if caregivers name objects with synchronous movement, vs. asynchronous or no movement, infants are more likely to attend to the object, look between object and parent, and show better word learning (Gogate et al., 2006).

Aside from this human infancy research, the potential benefits of "embodied," or gesturally enacted communication for spoken language acquisition are also suggested by work on non-human primate communication and sign language. First, the *iconic* properties of primate and human-signed gestures suggest a more direct relation to referential spoken language than do non-referential vocalizations (Corballis, 2010; Perniss and Vigliocco, 2014). Second, neurological research shows that AON regions implicated in hand and arm movements are closely located to those for mouth movements, suggesting the possibility of a close functional relationship (Fogassi and Ferrari, 2007; Corballis, 2010).

Special Linguistic Characteristics of Book-Sharing

In addition to "pointing and naming," it is well-established that certain forms of parental speech are privileged in the book-sharing context (e.g., Hoff-Ginsberg, 1991; Adrian et al., 2005; Salo et al., 2016; Noble et al., 2018). This is particularly so when using picture books where, rather than relying on a prespecified text, parents instead construct their own account of the book content and adjust it to their child (Sénéchal et al., 1995) in a process of "meaning-making" (Tronick, 2009). Importantly, these speech characteristics are precisely the ones that best promote child language development [being responsive to the infant's behavior and vocalizations, elaborative, and soliciting of child involvement (Snow and Ferguson, 1977)], and that foster child socio-cognitive understanding [mental state terms, complement clauses that include the content of someone's thoughts (Peskin and Astington, 2004; Brandt et al., 2016; Devine and Hughes, 2019; Boeg Thomsen et al., 2021)]. These speech forms in DBS are embedded in dynamic intersubjective exchanges with the child, in tandem with animated vocalizations and gestures, as described above; and they help scaffold the infant's attention and their understanding of the book content by highlighting individual elements of the picture and relating them to each other in a way that is constantly adjusted to the child's age, competence and wider experience, as well as their concurrent behavior (see **Figure 2**).

DISCUSSION

A natural propensity to share meaning via iconic forms developed in our early evolutionary history, advancing new kinds of cognition and communication, including protolanguage. We argue that this natural propensity can be harnessed, even in young infants, by the provision of books with pictorial content, and powerfully exploited to enhance infants' wider cognitive development via DBS, with specific adult behaviors (e.g., gaze-following) having been shown to benefit foundational skills for child literacy and educational progress. While some of this evidence derives from experimental studies investigating single aspects of adult behavior, DBS is an intersubjective process of dynamic engagement, with each partner adjusting what they do to the other's interest and emotional expressions and, in the case of parents, their child's competence and wider experience. Notably, while constituting "intuitive parenting," adult DBS practices can remain latent unless facilitated by support for parents' awareness of infant experience and capacities, and by guidance in the use of specific techniques. This is particularly likely where intuitive parenting practices are strained, for example, by adversity or mental health problems, or where local cultures prioritize different parenting and developmental goals (Murray et al., 2019). Accordingly, it is important that effective training programmes have been developed that promote good DBS practice and improved child outcome (Dowdall et al., 2020), particularly in contexts where low literacy rates and educational failure are major problems. While our discussion has mainly concerned evidence from WEIRD (Henrich et al., 2010) populations, and more investigation is required from wider cultural contexts to identify other patterns of parent-child interaction that are also developmentally beneficial (see Akhtar and Gernsbacher, 2008), it is nevertheless the case that, in the current global climate, literacy is the single most powerful route out of poverty (UNESCO Institute for Statistics (UIS) the Global Education Monitoring (GEM) Report, 2017; Dowd et al., 2018; RISE, 2020), particularly for girls, and opening up this potential to disadvantaged populations—for example via promotion of book-sharing—stands to be a powerful way to reduce economic inequality.

ETHICS STATEMENT

Written informed consent was obtained from the individual(s), and minor(s)' legal guardian/next of kin, for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

LM produced the first draft of the manuscript. All other authors contributed equally to developing the line of argument and the editing to produce the final manuscript.

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REVIEW
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Intersubjectivity and the Emergence of Words

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Intersubjectivity refers to two non-verbal intersubjective relations infants experience during their first year that are precursors to the emergence of words. Trevarthen, a pioneer in the study of intersubjectivity, referred to those relations as primary and secondary intersubjectivity. The former, a dyadic coordination between the infant and her caregiver, begins at birth. The latter, a triadic coordination that develops around 9 months, allows the infant and a caregiver to share attention to particular features of the environment. Secondary intersubjectivity is crucial for an infant's ability to begin to produce words, at around 12 months. Much research on the social and cognitive origins of language has focused on secondary intersubjectivity. That is unfortunate because it neglects the fact that secondary intersubjectivity and the emergence of words are built on a foundation of primary intersubjectivity. It also ignores the evolutionary origins of intersubjectivity and its uniquely human status. That unique status explains why only humans learn words. This article seeks to address these issues by relating the literature on primary intersubjectivity, particularly research on bi-directional and contingent communication between infants and mothers, to joint attention and ultimately to words. In that context, we also discuss Hrdy's hypothesis about the influence of alloparents on the evolution of intersubjectivity.

Keywords: intersubjectivity, bi-directional communication, dyadic relationship, triadic relationship, contingency, joint attention, words

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INTRODUCTION

> "Before language, there was something else more basic, in a way more primitive…that propelled us *into* language…that something else was *social engagement with each other*. The links that can join one person's mind with the mind of someone else—especially, to begin with, emotional links—are the very links that draw us into thought…The foundations of language were laid at the point when ancestral primates began to connect with each other emotionally in the same way that human babies connect with their caregivers" (Hobson, 2002, p. 2 italics in original).

Social and emotional non-verbal engagement between an infant and her caregiver are, as noted in the epigraph, crucial for the growth of language. These early forms of engagement are precursors of an infant's first words and are referred to as intersubjectivity, the focus of this

article. Our goal is to show why intersubjectivity is necessary for an infant's acquisition of words and for the emergence of words in our evolutionary history.

The evolution of language has been described as "the hardest problem of science" (Christiansen and Kirby, 2003). That is because many scholars have regarded language as a singular event. As such, the theory of evolution cannot explain it.

At the very least, language consists of words and grammar. Here, we are concerned with the emergence of words, rather than grammar, because words emerge before grammar, both phylogenetically and ontogenetically (Studdert-Kennedy and Terrace, 2017). We argue that the social foundations for the emergence of words provide a partial, but nevertheless important, answer to the hardest problem.

How Does Intersubjectivity Lead to Words?

Trevarthen, the premier theoretician of intersubjectivity, argued that words emerge at the end of the first year because of the cumulative effect of the two stages of intersubjectivity: primary and secondary. Primary intersubjectivity refers to reciprocal emotional and attentional coordination between an infant and a caregiver during face-to-face interaction, a dyadic relation that begins at birth. Secondary intersubjectivity, which typically begins toward the end of the first year, refers to a triadic relation between an infant, her caregiver, and nearby objects to which they jointly attend. It is based on the cooperative exchange of referential gestures between an infant and her caregiver (Trevarthen and Hubley, 1978; Hubley and Trevarthen, 1979).

The production of words, at about 12 months, is a crowning achievement of secondary intersubjectivity. Unfortunately, that achievement led many psychologists interested in the origin of words to focus more on secondary than on primary intersubjectivity (e.g., Bates et al., 1979; Nelson, 1996a,b; Tomasello, 1999). It not only implies a discontinuity in the development of intersubjectivity, but it also overlooks the fact that *secondary intersubjectivity could not emerge without primary intersubjectivity*. Emotional and attentional sharing are needed for the acquisition of words.

We agree with Trevarthen's view that progress toward the emergence of words is gradual, that it begins at birth, and that it encompasses both primary and secondary intersubjectivity. Here, we review recent studies that describe the nature of this development and the continuity of primary and secondary intersubjectivity. We also note that much additional work remains to be done.

How does the emergence of words in our evolutionary history inform our understanding of the development of words? As noted earlier, the theory of evolution cannot explain the origin of language as a singular event. Intersubjectivity is a missing link. Although animals can perceive emotions in others, they are limited in their ability to share them. Intersubjectivity allows that to happen, first by sharing emotion and attention dyadically, then by sharing attention to objects and, ultimately, by the exchange of words.

We end the article with a discussion of why intersubjectivity became crucial for the emergence of words in our evolutionary history. In that context, we describe Hrdy's theory of how intersubjectivity evolved from the practice of collective breeding by recent ancestors (Hrdy, 2009; Hrdy and Burkart, 2020). While discussing the emergence of words, we define them in a way that not only distinguishes them from the signals that animals use to communicate, but also shows why they are uniquely human.

We begin by describing basic features of primary and secondary intersubjectivity, as defined by Trevarthen, and more recent developments, such as "protophones," a precursor of babbling, that has some of the functional properties of words. We return to protophones at the end of the article to note that they may have played a prominent role in the evolution of words (Oller and Griebel, 2021).

PRIMARY INTERSUBJECTIVITY

Primary intersubjectivity is based on an infant's innate ability to coordinate gaze, vocalization, facial expression, and gesture with those of a parent. Such coordination is identified through correspondences in the form, timing, and intensity of these behaviors, and the contingencies (predictable sequences) that organize these exchanges.

Trevarthen discussed many examples of dyadic communication between an infant and her caretaker as instances of primary intersubjectivity. As opposed to experimental paradigms, such as imitation, those examples were drawn from observations of quasi-naturalistic, ongoing face-to-face communication. This article limits itself to such studies.

To study primary intersubjectivity, Trevarthen and subsequent researchers videotaped mothers and infants, seated face-to-face, using two cameras, one aimed at the mother, the other at the infant, generating a split-screen view (Stern, 1971; Brazelton et al., 1974; Trevarthen, 1977, 1980). Mothers were instructed to play with their infants as they would at home. Researchers could then rate the behavior of mothers and infants for variables, such as gaze direction, facial expression, vocal affect, head orientation, and touch.

The method of microanalysis was used to analyze such interactions. Beebe (2014, p. 4) described how microanalysis reveals coordination between an infant and her mother that is "so rapid and subtle that they are not quite grasped in real-time. By slowing down the movements, frame-by-frame microanalysis identifies remarkably beautiful moments, such as both partners rising up…into glorious sunbursts of smiles. It also reveals very disturbing moments, such as maternal anger or disgust faces, or infants becoming frantically distressed or frozen in alarm." The tiny behaviors revealed by microanalysis, such as rapid shifts of gaze, head, hand, mouth-opening and closing, are often as short as 250 ms (Beebe, 1982).

The Newborn's Preparedness for Primary Intersubjectivity

Infants are born prepared to engage in primary intersubjectivity. Evidence to support that view comes from an infant's sensitivity

and responsiveness to a caregiver's voice, facial expressions, and gestures. Sensitivity to a mother's voice is actually present prior to birth. The fetus can recognize the mother's voice and can respond to auditory stimuli from as early as the 26th week of gestation (Eisenberg, 1976). Components of speech, such as pitch, rhythm, stress, and some phonetic information, can be transmitted through the uterus (DeCasper and Fifer, 1980; Querleu et al., 1988; Lecanuet and Granier-Deferre, 1993).

Prenatal exposure to the mother's voice has been shown to affect postnatal auditory preferences. At birth, newborn infants prefer to listen to their mothers' voice (DeCasper and Fifer, 1980; Fifer and Moon, 1989) and can recognize speech samples from stories read to them prenatally by their mothers (Decasper and Spence, 1986). Neural evidence suggests that prenatal experience with language configures the neonate's brain to be responsive to the language heard prior to birth (May et al., 2011).

Protoconversation

Infants and caregivers engage in dyadic exchanges of attention, vocalization, and facial expression. These exchanges are referred to as protoconversations. The scope of protoconversations is illustrated in **Figure 1**, which shows some of the channels of communication between an infant and her mother. Trevarthen commented that: "…*subtle timing and complementary emotional expressions in protoconversations by 2-3-month-olds was perceived to be preparatory to linguistic communication*… they achieve their meaning…by exercise of non-linguistic forms of facial, vocal, and gestural expression and interaction with partners" (Trevarthen, 1998, p. 18, italics in original).

Trevarthen (1979) credits Bateson (1979) with the discovery of protoconversation. She described an important turn-taking relation between the utterances of 2-month-old infants and their mothers. In response to the mother saying for example, "What you going to say?," "Huh?," "Oh my!," "You going to be a good boy today?," the infant often responded by cooing, grunting, whimpering, and making other infant sounds (Bateson, 1979, p. 104). The onsets of the mother's comments and the infant's responses were strongly correlated. Because there was little temporal overlap between those utterances, Bateson referred to them as "protoconversations." Infants and mothers frequently alternate their utterances, just as adults do when they use language to converse.

Stern et al. (1975) argued that caregivers of 3–4-month-old infants have two modes of vocal interaction: simultaneous and turn-taking. Stern et al. (1975) termed these modes "coaction" and "alternation." In coaction, an infant and her caregiver's vocalizations overlap, as for example, when the infant cries and the caregiver attempts to soothe the infant vocally. In alternation, infant and caregiver take turns, as in protoconversation. Malloch and Trevarthen (2009) identified a narrative structure within these protoconversations, evident in the timing and reciprocity of the gestures and utterances (Delafield-Butt and Trevarthen, 2015), a structure that Dan Stern first described as "proto-narrative" (Stern, 2000).

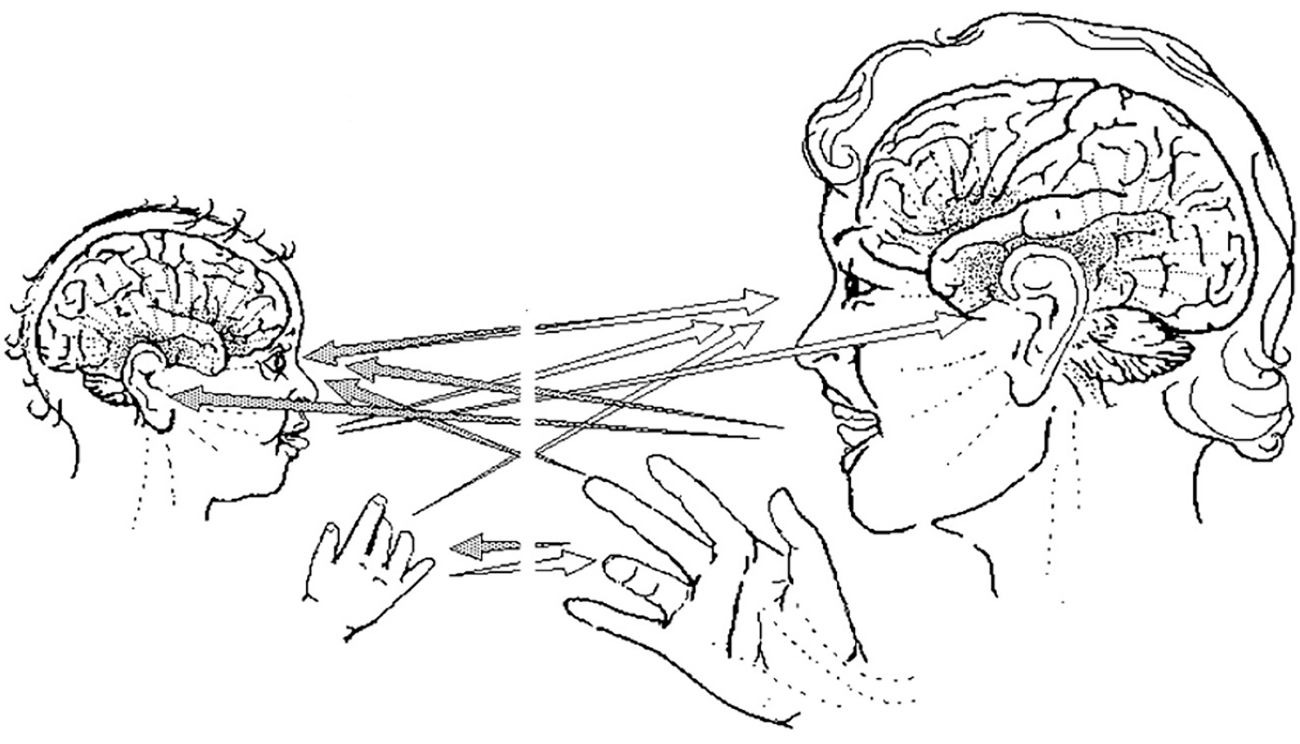

FIGURE 1 | Illustration of multiple channels of protoconversation between an infant and her mother (Trevarthen et al., 2006, Figure 12).

Protophones Within Protoconversation

In a groundbreaking research program, Oller (2000) showed that protoconversations actually begin shortly after birth. Infants engage vocally with their caretakers by uttering "protophones," primitive precursors of speech that consist of squeals, growls, and vowel-like vocalizations, called *vocants*. Squeals are vocalizations that are of a "notably higher than normal range of the infant"; growls, "notably lower than the normal range," and vocants, "in the mid pitch range of the infant" (Oller et al., 2013, supplement, p. 19).

A remarkable feature of protophones is their dual function. In addition to their use in protoconversation, they often occur endogenously, not directed at anyone (Long et al., 2020; Oller et al., 2021). Only humans, among primates, have been shown to produce endogenous vocalizations (Oller et al., 2019).

Infants need no encouragement to vocalize. Indeed, they seem to produce protophones to explore sound with no purpose other than to hear their own voice. Protophones therefore form the foundation of infants' vocal interactions. In their use in protoconversations, protophones provide one of the most important channels of primary intersubjectivity.

Oller distinguished protophones from cries, laughter, and vegetative sounds (coughs, sneezes, burps, etc.) because the functions and affective states of the latter utterances are fixed and are shared with other species. In contrast, protophones have "functional flexibility" in that they can be used in any affective state. This functional flexibility allows protophones to play an important role in language development. Like words, protophones do not have species-specific meaning: "Early protophones have a special role in language development and evolution because they are the first sounds to be free of specific fixed functions and thus reveal…the flexibility required for language" (Oller et al., 2013, p. 6322).

Functionally flexible protophones can express "positive, negative, and neutral emotional states on different occasions" (Oller et al., 2013, p. 6318). After an infant utters a protophone, her caretaker's response is based on intuitive judgments of the infant's affect while producing that protophone. In response to an infant's protophone, such as a squeal, a caregiver might respond with positive affect if the squeal was accompanied by positive affect. When the same sound is expressed with neutral affect, the caretaker might respond in kind. If the squeal is expressed with negative affect, the caretaker might vocalize with a sympathetic sound.

Such observations suggest that protophones can be detached from any particular emotional state, similar to the way that words can be used to represent different emotional states. That type of flexibility has not been reported in non-human primate vocalizations.

From birth, protophones occur at substantially higher frequencies than stereotyped species-specific vocalizations, such as cries (Oller et al., 2013). Yoo et al. (2018) were the first to investigate the temporal relation between an infant's protophones and cries, and a caregiver's vocal response. Even during the infant's first 3 months, caregivers were likely to take turns interacting with protophones, but not with cries. When an infant produced protophones, mothers often responded in a protoconversational manner.

Turn-Taking and Protoconversation

Vocal turn-taking provides a key pattern of interaction that organizes exchanges during primary intersubjectivity. Turn-taking is not, however, unique to humans. Members of many non-human species take turns while interacting with one another (Pika et al., 2018). Examples can be found in all major branches of primates (Levinson, 2016), in non-primate mammals [whales (Miller et al., 2004; Schulz et al., 2008; Morisaka et al., 2013), dolphins (Lilly, 1962; Nakahara and Miyazaki, 2011), bats (Carter et al., 2009), and elephants (Leighty et al., 2008)], in more than 100 different species of birds (Dahlin and Benedict, 2014), and even in insects (Mason, 2009).

In these species, the functions of turn-taking include mutual recognition, maintenance of contact between partners, mutual defense of territories, reproductive synchrony, and mate location. In many instances, the structure of turn-taking is similar to that of humans. Turns are relatively short (from less than a second to a few seconds) and the gap between turns is brief (often as little as 200 ms). Similarity in the form and structure of turn-taking in non-human species and humans notwithstanding, there are fundamental differences in content and modality.

Regarding content, turn-taking responses in non-human species are fixed in that they vary little over successive turns. In humans, the content is arbitrary, that is, variable and flexible. Evidence can be found in vocal exchanges between infants as young as 2 months and their caregivers (e.g., Bateson, 1979). As noted in the previous section, an infant's affect varies in such exchanges. At 3 months, the quality of the infant's utterances varies as a function of whether she is responding contingently to her mother's vocalizations (Bloom et al., 1987; Gratier et al., 2015).

Regarding modality, most studies of turn-taking in humans focus on vocalization or speech. It has recently been shown, however, that turn-taking occurs in exchanges of sign language (de Vos et al., 2015). That suggests that spoken and sign languages follow similar time courses in the planning and production of conversational utterances. The multiple modalities of gesture and voice produce what Trevarthen and Delafield-Butt (2013) identify as the origin of an invariant "narrative" form in pre-verbal protoconversation.

Babbling and Phonetic Perception

Canonical babbling begins at about 6 months (Vihman, 2014), and may originate in infants' endogenous vocal exploratory activity. It is characterized by syllables with at least one vowel-like element and one consonant-like element, with a rapid, adult-like transition between consonant and vowel [phonetical representation: for example, (ba), (di), and (da)]. The rapid transition between consonants and vowels is a defining feature of the difference between pre-canonical and canonical syllable productions.

Mother–infant interactions are the prominent social context influencing infants' canonical babbling. Goldstein and Schwade (2008) showed that 9-month-old infants modify their canonical babbling in response to their mothers' contingent utterances. Under a contingent condition, mothers were asked to respond to their infants' babbling either by speaking a resonant vowel or by speaking a word that alternated a consonant and a vowel. Under the non-contingent condition, recordings of the mother's responses were not synchronized with the infant's babbling.

Infants given contingent feedback restructured their babbling by incorporating patterns of their mother's speech. Infants given non-contingent feedback did not incorporate patterns of their mothers' speech.

Infants hearing contingent resonant vowel responses increased their resonant vowels. Similarly, infants hearing contingent words with consonant–vowel sounds increased the frequency of their consonant–vowel syllables. Although the sounds the infants produced were likely already in their repertoire, there was an overall increase in the frequency of particular phonemes. These phonemes reflected the mothers' patterns of speech. In this manner, maternal speech influences infants' canonical babbling, an important step in word learning.

Related research provides evidence of phonetic perception. Unlike adults, young infants readily discern phonetic properties used in languages to which they have not been exposed (Eimas et al., 1971). But this ability declines sharply between 6 and 12 months of age (Werker and Tees, 1984). Kuhl et al. (2003) exposed 9-month-old English-learning infants to Mandarin in 12 lab sessions. The infants exposed to Mandarin continued to perceive the phonetic properties of Mandarin, but that ability declined in control infants. However, the ability to perceive the phonetic properties of Mandarin was found only if the exposure was from live interactions between Mandarin speakers and the infants, rather than from video or audio-only exposure to the same Mandarin speakers. Similarly, when 9-month-old English-learning infants were exposed to 12 sessions with Spanish speakers in live interactions with toys, infants' social engagement with the Spanish speakers predicted their phonetic discrimination of Spanish (Conboy et al., 2015). As noted by Kuhl et al. (2003), an infant's ability to neurally code the phonetic properties of language interacts with the social context in which language is heard.

SECONDARY INTERSUBJECTIVITY

Secondary intersubjectivity generally emerges between 9 and 12 months and includes joint attention. Joint attention refers to the *triadic* coordination of an infant and her caregiver with objects or events in the immediate environment. It is based on sharing one's attention, feelings, and intentions with regard to external objects (Trevarthen and Hubley, 1978; Trevarthen, 1993). As we argue below, joint attention is crucial for the production of an infant's first words.

The transition from dyadic forms of shared attention and emotion during face-to-face interaction to triadic forms of shared attention is one of the most dramatic developments during an infant's first year. Whereas shared attention (parallel looking) is not uniquely human, joint attention is (Tomasello, 1999; Tomasello et al., 2005; Zlatev, 2008). For example, when two chimpanzees orient to the same object, or when one chimpanzee follows another's gaze, they share attention to that object.

What is missing in this and in other examples of shared attention is visual and/or emotional acknowledgment that they each see the same object. Consider an infant who points to an object to which her caregiver is attending, and then gazes at her caregiver. That is evidence of what Bruner (1975) described as a "meeting of the minds," or what Tomasello (1995) subsequently referred to as "knowing together."

Joint Attention

Shared attention and reciprocal acknowledgment of such attention are necessary for the establishment of joint attention. The difference between these phenomena is shown in **Figure 2**.

What makes attention *joint* is shared attention to an object that includes reciprocal acknowledgment of that sharing (Carpenter and Call, 2013). The thin arrows in **Figure 2** illustrate shared attention (parallel looking). The bold arrow represents bi-directional sharing, some form of social behavior, for example, looking, smiling, vocalizing, that acknowledges that each individual knows that they are both looking at the same object.

Joint attention is critical to our argument that early intersubjectivity contributes to the emergence of words because joint attention predicts subsequent language outcomes, for example, the age at which words are first produced and vocabulary size (Tomasello and Todd, 1983; Tomasello et al., 1986; Tamis-LeMonda et al., 1996; Carpenter and Call, 2013).

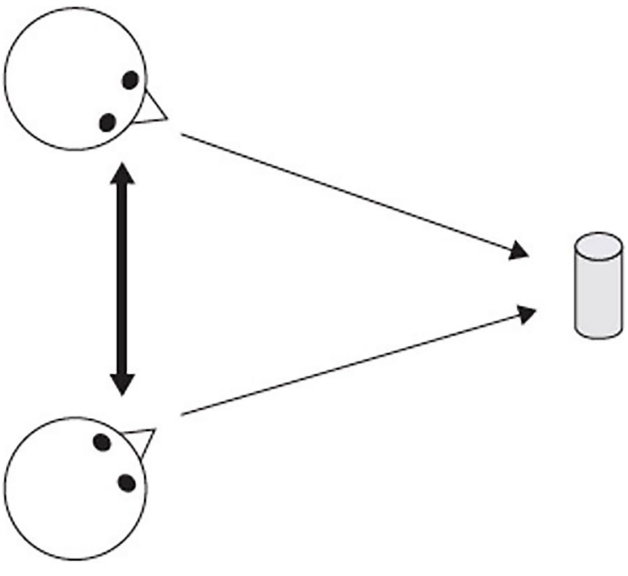

FIGURE 2 | The joint attention triangle. The bold arrow represents how two individuals "know together" that they are sharing attention to the same object. Adapted from Figure 2.1 of Carpenter and Call (2013).

The Continuity vs. Discontinuity Debate Between Primary and Secondary Intersubjectivity

Many psychologists interested in the origins of words have ignored the contribution of primary intersubjectivity to the emergence of secondary intersubjectivity that culminates in word learning (e.g., Bates et al., 1979; Nelson, 1996a,b; Tomasello, 1999). For example, Tomasello (1999) has been a strong advocate of a discontinuity between primary and secondary intersubjectivity. As evidence, he cites a "9-month cognitive revolution" in which infants acquire shared intentionality, the motivation to share attention with others (see Racine et al., 2014). That includes the ability to perceive that another is attending to the same object as the self. The 9-month revolution is based on experiments on imitative learning, social referencing, goal detection, and other joint attentional capacities that emerge between 9 and 12 months (Carpenter et al., 1998). The results of those experiments led Tomasello to reject Trevarthen's position of strong continuity between primary and secondary intersubjectivity.

Although Tomasello and his colleagues have amassed evidence that 9-month-old infants exhibit shared intentionality, we argue that shared intentionality is built on the foundation of primary intersubjectivity. One cannot share attention triadically until it can be shared dyadically (Oller, 2000; Oller et al., 2016). Longitudinal studies show no evidence that infants begin joint attention before experiencing extensive dyadic interaction (Oller, 2000; Legerstee et al., 2007; Bigelow et al., 2010). Logically and empirically, triadic interactions incorporate dyadic sharing.

The "9-month revolution" is based on a combination of factors that have their origins in primary intersubjectivity. These include the role of early dyadic interactions, mother and infant reciprocal contingent coordination in these early interactions, and how infants interact with objects before 9 months.

WHAT IS THE EMPIRICAL EVIDENCE THAT PRIMARY AND SECONDARY INTERSUBJECTIVITY ARE CONTINUOUS?

Commenting on the literature's disconnect between primary and secondary intersubjectivity, Legerstee et al. (2007, p. 298) provided the following diagnosis:

> The problem is that theorists who propose that infants do not engage in triadic engagement until 9 months of age seldom investigate infants below these ages (Tomasello, 1995; Carpenter et al., 1998), whereas those who argue for a relationship between dyadic and triadic communication seldom venture beyond the age of 3 months (Tronick et al., 1978; Tronick, 1981; Murray and Trevarthen, 1985).

There are, however, some suggestions of continuity between primary and secondary intersubjectivity. In what follows, we describe how interactions in *early infancy* relate to joint attention and the production of words toward the end of the first year. We first present evidence that infants engage with mothers around objects earlier than the 9-month revolution that Tomasello proposed.

Early Mother–Infant Engagement With Objects

Some studies have examined infant–adult triadic engagement with objects under 9 months of age. For example, de Barbaro et al. (2013) measured shifts in mother–infant sensory-motor coordination longitudinally, while infants were looking at or manipulating toys at ages 4, 6, 9, and 12 months. At 4 months, infants attended to a single toy at a time, with mothers engaged in active scaffolding by moving toys toward or away from the infants. At 6 months, infants maintained prolonged attention to their toys, often sharing that attention with their mothers. At 9 months, infants were able to handle two toys simultaneously, and bouts of mother–infant turn-taking occurred around their shared interest in objects. At 12 months, infants often verbalized while watching their mothers and attempted to imitate their mothers' actions on the toys. At each age, de Barbaro et al. (2013) documented that infants' actions on toys enhanced those observed earlier, showing continuity in how infants engage with objects. Importantly, infants smiled and gazed at their mothers while playing with toys prior to 9 months.

Grossmann and Johnson (2010) explored the activation of 5-month-old infants' prefrontal cortex during joint attention with an adult and an object. The prefrontal cortex of the brain is activated during joint attention in adults (Schilbach et al., 2013). At 5 months, infants shared looks to an adult and object. Like adults, the left dorsal prefrontal cortex was activated when they engaged in joint attention. The authors speculated that the human infant is neurobiologically prepared to participate in joint attention and that this ability is available at 5 months.

Striano and Bertin (2005) examined mother–infant and stranger–infant engagement with objects longitudinally at infant ages 5, 7, and 9 months. They showed that infants coordinated attention to an object with mother, and with a stranger, at 5 and 7, as well as 9 months. Triadic coordination of attention with positive affect increased gradually, rather than abruptly, from 5 to 9 months.

The research described in this section on the ways that infants coordinate interest in toys and engagement with their caretakers suggests that Tomasello's "9-month revolution" is actually an incremental process that begins at 4 months. Infants gradually integrate objects into their dyadic interactions.

EXPANDING THE DOMAIN OF PRIMARY INTERSUBJECTIVITY

In this section, we describe research on mother–infant interaction in the first few months of life, in particular the importance of contingency in early mother–infant interactions, and how experimental disruptions of contingency can disturb them.

We describe research that explores the development of the coordination of face-to-face exchanges across the first few months, especially the salience of bi-directional vocal exchanges. We then consider how early contingent interactions are related to joint attention and the emergence of words.

The insightful descriptions of primary intersubjectivity by Trevarthen (1979) were based mainly on single case or small N studies. Subsequent research with larger samples provided an expanded description of how mothers and infants engage in face-to-face communication during primary intersubjectivity.

Trevarthen argued that primary intersubjectivity was organized by *correspondences and contingencies of behavior* between mother and infant (Beebe et al., 2003). Correspondences include matching of form, timing, and intensity of behaviors, for example, both partners smiling, vocally pausing for similar durations, or both emitting a high-pitched squeal.

Contingency

Whereas correspondences involve particular behaviors per se, contingency addresses the structure of behavioral sequence across time. *Contingency* refers to sequential constraint: a significant probability that a prior behavior predicts a subsequent behavior. Recent studies on the early development of primary intersubjectivity have focused more on contingency of interactions than on correspondences of form.

In a study of mother–infant face-to-face communication at infant age 4 months, which coded second-by-second behavior from split-screen video and assessed contingency using time-series models, Beebe et al. (2016) showed contingent coordination between mother and infant facial affect, vocal affect, head orientation, and gaze. Contingent coordination was bi-directional, that is, mothers' behavior affected that of infants, and vice versa. Across the group, in all the modalities assessed, each partner followed the direction of the other's change.

Figure 3 shows an example of contingent coordination (Beebe et al., 2016), by depicting second-by-second ratings of mother and infant facial affect during face-to-face interaction. It shows how mothers and infants closely followed each other's direction of affect change.

Beebe et al. (2016) also showed that this bi-directional process was *asymmetrical*. Mothers coordinated and adjusted their contingent behaviors to their infants more than infants adjusted to their mothers. That asymmetry is important in understanding that the mother has a key role in providing the conditions in which this bi-directional interactive process develops. Maternal contingent responsiveness is important to the infant's increasing social capacity that will lead to joint attention and words. But despite this asymmetry, infants have a powerful role in these interactions and, ultimately, it is the infant's contingent vocal response that will lead to the onset of words.

Infants are sensitive to the ways in which their behaviors are responded to contingently by social partners (Murray and Trevarthen, 1985; Tamis-LeMonda et al., 2001). Others' contingent responsiveness to infant behavior leads infants to expect that they can affect their partner's behavior through their own actions, enhancing their sense of agency (Tarabulsy et al., 1996; Haith and Benson, 1998; Harrist and Waugh, 2002; Bigelow and Rochat, 2006). Infants are aware of their agency very early, possibly from birth or even earlier, as demonstrated by their actions on their own bodies (Rochat and Striano, 2000) and in the physical environment (Watson, 1979). However, when in interactions with others during primary intersubjectivity, infants' awareness of their agency increases as they notice the effect of their behavior on others.

Disruptions of Contingency

Responses of infants to Still Face and Replay experiments provide further evidence of infant expectancies. Not only are expectancies an important foundation of the infant's communicative capacity (Fagen et al., 1984; Tronick, 1989; Gros-Louis et al., 2014), but they are also critical in the development of joint attention, which requires the expectation of being able to influence a partner's attentional focus.

In the Still Face Paradigm, mothers and infants engage in a face-to-face task in three phases (Tronick et al., 1978). Initially, mothers and infants interact as they normally would, providing a baseline. Mothers are then instructed to become completely still-faced, looking at the infant with a neutral expression, without touching or talking. Finally, they resume normal interaction.

If the infant expects the mother to be responsive, the still-face phase should violate that expectation, and the infant should react differently in the still-face phase than in the baseline or resumption of play phases. Such changes are reliably seen from 2 months of age (Mesman et al., 2009). Infants reduce their attention and positive affect when the mother becomes unresponsive during the still-face phase, as compared to the interactive phases.

The Replay Task provides an even more stringent test of the infant's expectations of contingent responsiveness (Murray and Trevarthen, 1985). Mothers and infants engage over closed-circuit TV, which does not disturb mutual contingent responsivity. First mothers and infants interact as they normally would. Then the infants view a replay of the *previous* interaction, such that the mother's responsiveness to the infant's current behavior is absent. By 4 months (Hains and Muir, 1996; Bigelow and Decoste, 2003), and in some studies earlier (Murray and Trevarthen, 1985; Nadel et al., 1999), infants respond to the replay phase much like the still-face phase. These studies show that infants have developed expectations for their mother's contingent responsiveness, not just expectations for infant-directed facial expressions and vocalizations.

These experimental disruptions of contingency indicate that infants are very sensitive to the contingency structure and that ordinary ongoing infant social behavior is disturbed when contingency is disrupted. The nature of the contingency structure is thus a key aspect of primary intersubjectivity.

Early Developmental Changes in Mother–Infant Face-to-Face Interaction

Most research on face-to-face communication during the period of primary intersubjectivity has focused on infants

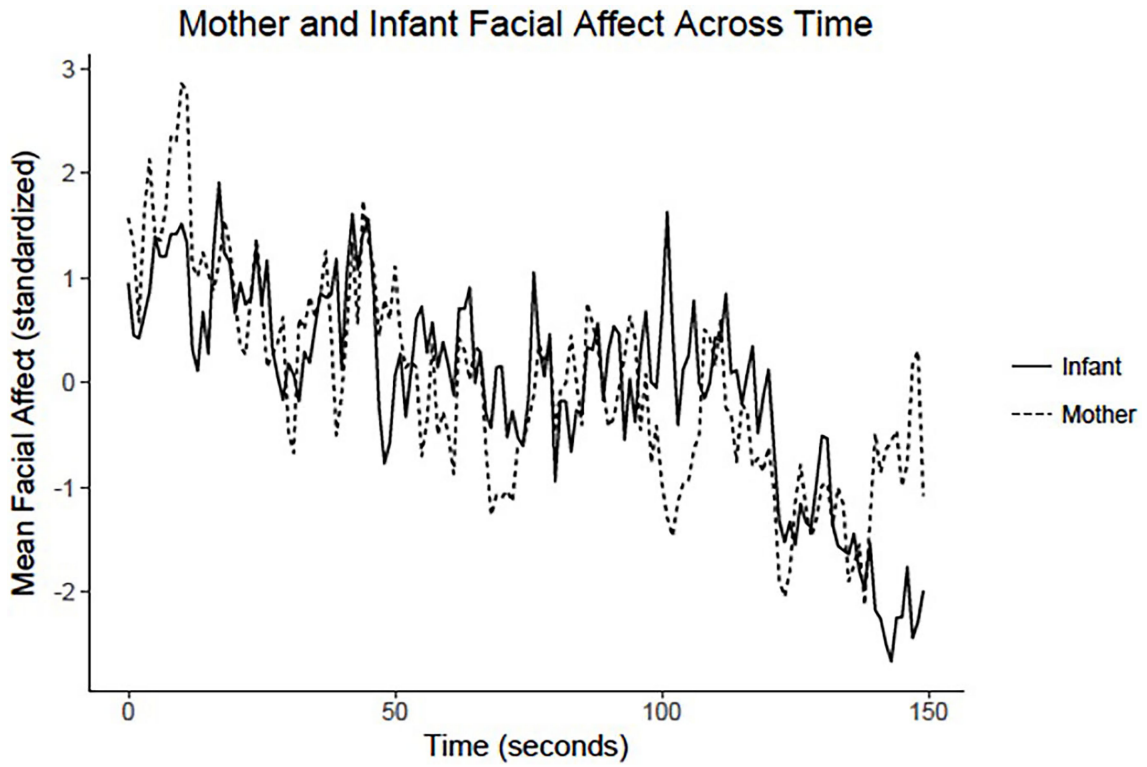

FIGURE 3 | Second-by-second ratings of mother and infant facial affect during sessions (150 s) of mother–infant dyads. This illustration of mothers and infants following the others' direction of affect change is based on an across-group ($n = 132$) documentation of bi-directional contingent coordination *via* multi-level time-series modeling (Beebe et al., 2016). See text for additional details. Data obtained from Table 1 of Beebe et al. (2016).

at 3–4 months. By that time, mother–infant bi-directional contingent coordination is well-established (Cohn and Tronick, 1988; Beebe et al., 2016). There are, however, important developments prior to this time that allow us to observe the growth of such coordination.

A major shift in infant perceptual-motor abilities occurs around 2 months. These include increases in the infant's ability to maintain an upright posture, to sustain visual attention, and to explore the internal features of the partner's face. Such changes facilitate the infant's capacity for face-to-face interaction (Haith et al., 1977; Hopkins et al., 1990). Infants increase smiling and non-distress vocalizations (Trevarthen, 1979; Wolff, 1987). Infants also become more aware and interested in social partners (Rochat, 2001) and more responsive in interactions (Henning et al., 2005; Bigelow and Power, 2014; Beebe et al., 2016).

Yet even prior to 2 months, there is evidence of coordination between mothers and infants. For example, Murray et al. (2016) examined mother–infant interactions weekly during the infants' first 2 months. Although minimal, infants' social behaviors (non-distressed vocalizations, smiles) increased, particularly after 3 weeks. Mothers responded selectively to both infants' social and non-social behaviors. Importantly, mothers' mirroring (contingent behavior that matched the infants' behavior) and positive responses that elicited infants' attention (e.g., smiles, eyebrow flashes) were associated with increases in infant social behaviors.

Lavelli and Fogel (2005) examined mother–infant face-to-face interactions between birth and 3 months. Initially, infants exhibited little emotional expression. By the second month, however, they began to smile and coo and their attention became more sustained. Their behavior became linked with mothers' responses of smiling and talking. By the end of the second month, mothers increased their "mirroring" of infant actions by matching or elaborating infant action. Turn-taking dialogs emerged with mutual attentiveness and positive affect (Lavelli and Fogel, 2013). By 2–3 months, these bi-directional sequences of positive engagement became enhanced in both partners.

Infants may be prepared to be sensitive to specific maternal responses that match or positively respond to their own behaviors, even if those responses are relatively infrequent. Infants prefer "matching" (imitative/elaborative) over non-matching forms of responses (Meltzoff, 2007; Markova and Legerstee, 2008). These preferences may involve neural mechanisms that map observed and executed expressions. Young infants may sense equivalences when their gestures are immediately observed in similar actions of others, resulting in action-perception connections that strengthen the neural circuits involved, increasing the probability of the behaviors occurring (Murray et al., 2018). Such speculation is supported by behavioral imitation studies (Simpson et al., 2014; Meltzoff and Kuhl, 2016) and neurophysiological research (Rizzolatti and Fogassi, 2014; Tramacere et al., 2016).

Mothers' propensity to mirror (imitative/elaborative) and positively respond to certain infant behaviors over others may be a means for establishing shared communication that becomes developed and elaborated in culturally specific ways (Murray et al., 2018). More studies are needed to explore cross-cultural variations in mother–infant interactions, for example, in cultures where such interactions are less visual and more tactile (Keller, 2007; Kärtner et al., 2008, 2010; Negayama et al., 2015; Owusu-Ansah et al., 2019).

Early mother–infant interactions in non-human primates (e.g., lip smacking, mutual gaze) have been shown to affect later social–emotional functioning, suggesting an evolutionary history of early mother–infant communication patterns (Bard et al., 2005; Ferrari et al., 2009; Dettmer et al., 2016). There are, however, notable differences. In chimpanzees, these include very short durations of mutual gaze, infrequent maternal looking behavior, and the absence of such behavior after 3 months (Bard et al., 2005). Ape mothers provide caregiving and are responsive to their infants' needs, but they rarely respond to infant vocalizations with their own or vocalize independently to their infants (Oller et al., 2019). Primary vocal intersubjectivity is virtually absent and non-vocal primary intersubjectivity is far less frequent than in humans. Overall, mother–infant interactions in non-human primates are short-lived and bear little resemblance to those observed in humans.

Salience of Vocal Bidirectional Exchanges

Bi-directional mother–infant interactions involve all modality channels (Beebe et al., 2016). Yet by the third month, bi-directional vocal responses become particularly salient compared to bi-directional responses in facial affect (Lavelli and Fogel, 2013), at least in Western cultures where distal communication is the basis of mother–infant communication (e.g., Kärtner et al., 2010). This may be due to the ease with which infants can perceive the turn-taking quality of vocal exchanges. Mothers tend to stop talking when infants vocalize and resume talking when infant vocalization ends. Reciprocally, infants tend to become vocally responsive when mothers talk. Such interactions result in the easily recognized back and forth vocal exchanges, as first identified by Bateson (1979).

Bigelow and Power (2014) examined mother–infant face-to-face interactions at 1, 2, and 3 months and provided evidence of the primacy of vocal over facial contingency. The following patterns were observed in vocal, but not smiling exchanges. Vocal contingencies (vocal responses within 1 s of the partner's vocalization) of mother to infant, and infant to mother, were correlated at each age. Moreover, maternal vocal contingency at 1 month predicted infant vocal contingency at 2 months, and maternal vocal contingency at 2 months predicted infant vocal contingency at 3 months. However, *infant* vocal contingency at 1 and 2 months did not predict maternal vocal contingency at 2 and 3 months, respectively. Thus, for vocal exchanges, the mother leads or scaffolds the development of contingency processes across the first 3 months.

At the end of the third month, infant vocalizations take on a new, more speech-like quality in that they are less nasalized and more fully resonant (Bloom et al., 1987; Goldstein and Schwade, 2008). Adults perceive these vocalizations as more communicative (Beaumont and Bloom, 1993; Hsu and Fogel, 2003) and respond by adjusting their own emotional responses.

Infants participate in a basic dialogic vocal turn-taking structure. Jaffe et al. (2001) investigated those dialogs by examining vocal timing coordination during mother–infant and stranger–infant face-to-face interactions in 4-month-old infants. The focus was the coordination of vocalizations, pauses, and switching pauses at the point of the turn exchange; and in particular, vocal turn-taking through the contingent coordination of switching pause durations.

As illustrated in **Figure 4**, a turn begins when either participant vocalizes alone, and it is held until the other vocalizes alone, at which point the turn is exchanged. Switching pauses occur at the moment of the turn exchange.

Infants were active participants in bi-directional contingent coordination of vocalization, with both mother and stranger. In both mother–infant and stranger–infant interactions, partners coordinated vocal turn-taking rhythms by matching the durations of "switching pauses" at the moment of the turn exchange. That is, each partner paused for similar durations before the other took a turn.

Jaffe et al. (2001) also showed that mother–infant and stranger–infant vocal timing coordination predicted outcomes during secondary intersubjectivity, specifically, 12-month attachment and infant cognition (as measured by the Bayley Scales). Infant contingent coordination was as important as adult contingent coordination in predicting outcomes, a demonstration of the infant's role in development. Although the prediction of the Bayley Scales, a general cognitive measure, is not specific to the development of words, words develop in the context of a more general cognitive capacity.

Bornstein et al. (2015) expanded findings of Jaffe et al. (2001) in infants who were 5.5 months by documenting that dyadic conversational turn-taking exists in multiple cultures. Despite large differences in overall talkativeness of mothers and infants across the cultures, mothers' vocalizations to their infants were contingent on the offset of infants' non-distress vocalizations (within 2 s). Infants' vocalizations to mothers were likewise contingent on the offset of mothers' vocalizations.

Our expanded description of the domain of primary intersubjectivity shows that contingent coordination between mother and infant begins in the first months of life. Mothers scaffold the contingent process, but infants actively participate, and the process is bi-directional, although asymmetrical. Vocal (vs. facial) contingency is salient in this process.

MATERNAL CONTRIBUTIONS IN EARLY MOTHER–INFANT INTERACTIONS THAT LAY THE FOUNDATION FOR JOINT ATTENTION, AND ULTIMATELY FOR WORDS

Vygotsky (1978) and Trevarthen (1979) argued that maternal responsiveness in early interactions with infants is crucial for

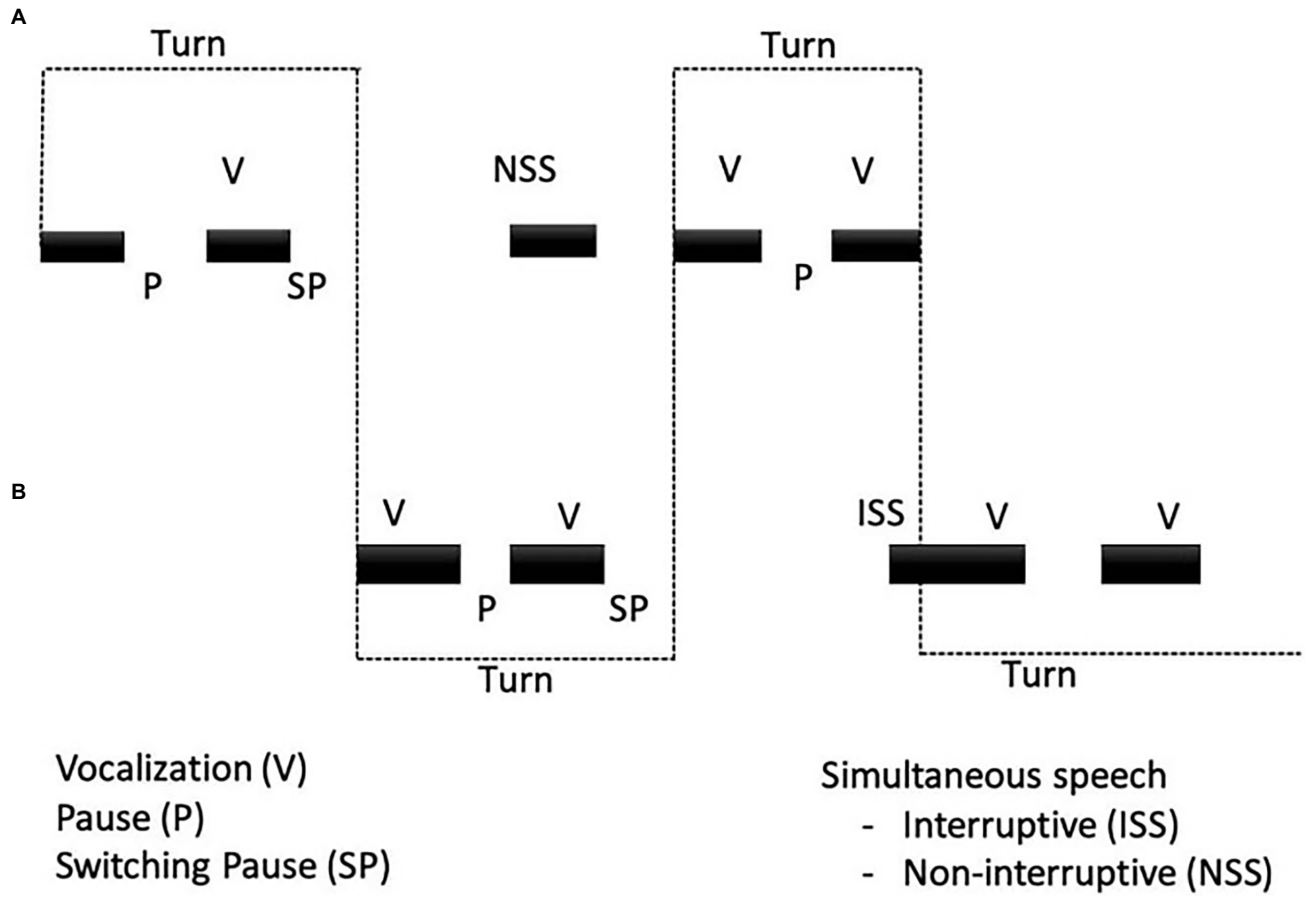

FIGURE 4 | (A) and **(B)** represent two partners. The individual gains the turn the instant she/he vocalizes unilaterally. The switching pause (SP), which occurs as turns are exchanged, regulates the timing of turn-taking. Courtesy of Beatrice Beebe, New York State Psychiatric Institute, Columbia University.

the development of an infant's capacity to engage in joint attention. Although there is relatively little evidence from studies of infants under 9 months, two research groups predicted joint attention from early mother–infant interactions.

Legerstee et al. (2007) studied mother–infant face-to-face interaction in young infants, in relation to infant joint attention at 10 months. At 3 months, infant gaze and maternal attunement were measured. Maternal attunement was defined as the degree to which mothers maintained attention and displayed positive affect. At 5, 7, and 10 months, mother–infant play was examined for coordinated joint attention. Measures included the extent to which infants and mothers attended to the same object and infants shifted gaze between the mother's face and the object. Infant gaze at 3 months predicted infant coordinated joint attention at 10 months, but only if maternal attunement was high at 3 months. These findings suggest that sensitive maternal attunement is a mechanism that fosters the link between dyadic and triadic interactions, that is, between primary and secondary intersubjectivity.

Bigelow et al. (2010) showed that mothers who were vocally contingent (within 1 s) to their infants' vocalizations during face-to-face interactions at 4 months provided more scaffolding of infants' joint attention (verbal encouragement, modeling, and turn-taking) at 15 months. Joint attention was defined as mothers and infants engaging with the same object and infants demonstrating awareness of the mother's involvement through gaze, gesture, or vocalization. These results support the importance of early maternal contingent responses during primary intersubjectivity for later triadic interactions.

Although the studies cited above predicted facilitation of infant joint attention from maternal behaviors during early interactions, there have been few investigations of how such maternal behaviors might directly predict infant word acquisition or later language skills. In one of the few relevant studies, Ruddy and Bornstein (1982) found that mothers who encouraged their infants' attention to objects during mother–infant play at 4 months had infants with larger speaking vocabularies at 12 months.

More recently, some studies have examined the relation between maternal behaviors during early mother–infant interaction and more long-term language abilities in children. Sheinkopf et al. (2017) found that mothers' positive affect (smiling, laughter, making playful faces) and infant-directed vocalizations during face-to-face interactions with 4-month-old

infants predicted the children's verbal IQ at 4.5 years (Wechsler Preschool and Primary Scales of Intelligence, Revised) and 7 years (Wechsler Intelligence Scale for Children, 3rd edition). Bornstein et al. (2020) found that maternal language to infants (amount and frequency) and maternal sensitivity (Ainsworth Maternal Sensitivity Scale, Maternal Behavioral Q-Sort) at 5 months each independently predicted core child language skills at 49 months.

Despite the dearth of studies of maternal behavior in early infancy that predict the emergence of words, maternal behaviors in early mother–infant interaction that facilitate later infant joint attention abilities can be inferred to enhance infant word acquisition. That is because the production of words is built upon the ability to engage in joint attention (Conboy et al., 2015). Infant joint attention interactions with mother predict subsequent vocabulary size and the age at which infants begin to use words (Tamis-LeMonda et al., 1996; Carpenter et al., 1998).

Mothers' speech to infants within joint attention is particularly facilitative of infant word learning if the mother's speech contingently follows (rather than redirects) the infant's object focus (Tomasello and Farrar, 1986; Akhtar et al., 1991; Dunham et al., 1993; Bigelow et al., 2010). Mothers tend to name objects that are in the center of the infant's visual field, thereby capitalizing on the infant's focus of attention and enhancing word learning (Yu and Smith, 2012; Pereira et al., 2014; Suanda et al., 2018). Thus, maternal speech contingent on infants' focus during joint attention may affect infant later word learning just as maternal contingent responsiveness within early face-to-face interaction affects later infant joint attention abilities (Legerstee et al., 2007; Bigelow et al., 2010). These findings support the argument for a continuity between early prelinguistic mother–infant interaction and infants' later emerging words. By contingently following the infant's lead in both primary and secondary intersubjectivity, mothers facilitate their infants' communicative abilities.

INFANT CONTRIBUTIONS IN EARLY MOTHER–INFANT INTERACTIONS THAT LEAD TO JOINT ATTENTION

What do we know about the nature of infant participation in early social interactions that might be relevant to infant capacity to participate in joint attention? Direct empirical evidence is scarce. As noted previously, however, Legerstee et al. (2007) found that infant gazing at their mothers (who provided high maternal attunement) predicted infants' later joint attention. In a rare study that documented the relation between infants' early social behaviors and their joint attention abilities in the second year, Salley et al. (2016) found that 4-month-old infants' social engagement with mothers in face-to-face interactions (proportion of time spent smiling, vocalizing, gazing) was associated with more frequent infant initiation of joint attention at 18 months. Infants' early social engagement behaviors are acquired in interactions with their mothers. These encounters generate infant expectations that their actions can affect the partner's behavior and thus enhance their sense of agency. Such abilities are crucial for later joint attention when infants engage and direct their partner's focus to objects of their own interest.

From the beginning of infants' increased interest in social interactions at 2 months, infants show a preference for the contingency levels they experience with their mothers. Bigelow and Rochat (2006) observed mothers and their 2-month-old infants who came to the lab in pairs. The infants engaged in face-to-face interactions with their mothers and with a stranger (mother of the other infant). Infants were most contingently responsive (smiled or vocalized within 1 s of the partner's smile or vocalization) to the stranger if the stranger's level of contingency to the infant was similar to that of the mother. Infants were less responsive to the stranger if the stranger's level of contingent responsiveness differed from that of the mother. Infants' preference for the contingency levels with which they are most familiar becomes even stronger by 4 months (Bigelow, 1998), showing infants' growing expectation for how their partner should respond. These findings support infants' preference for familiar contingency levels and their expectations for how interactions should unfold.

Infants' sense of agency in affecting their partner's behavior is apparent in the still-face phase of the Still Face Task when they demonstrate *social bids*. Social bids are smiles or non-distress vocalizations while looking at the unresponsive partner during the still-face phase. Tronick et al. (1978) were the first to suggest that these infant behaviors were efforts to elicit interaction with the unresponsive partner. Researchers have subsequently interpreted such behavior as social bids to re-engage the partner (Cohn et al., 1991; Delgado et al., 2002; Carter et al., 2008; Bigelow and Walden, 2009; Goldstein et al., 2009; Mcquaid et al., 2009; Franklin et al., 2014).

Infant social bidding behavior during the still-face phase is considered an example of infant independent initiative because social bids occur in the absence of the partner's social behavior. Social bids not only imply that infants are aware of the effects of their own behavior, but also that infants can initiate attempts to change the partner's behavior to repair the disrupted interaction. These are abilities that are important for joint attention, for in joint attention the infant can initiate the partner's engagement with objects as well as shift the partner's attention to objects that interest the infant.

Infant social bidding during the Still Face Paradigm is influenced by the degree of maternal contingency they previously experienced. In a longitudinal study with 1-, 2-, and 3-month-old infants, Bigelow and Power (2016) found that greater maternal vocal contingency in the baseline interactive phase of the Still Face Task at 2 and 3 months predicted greater likelihood of infant social bids to the mother in the still-face phase at 2 and 3 months, respectively. Moreover, maternal vocal contingency in the previous month (months 1 and 2) predicted infant social bids during the still-face phase at 2 and 3 months.

These findings illustrate the importance of an expanded view of primary intersubjectivity. The nature of maternal contingent coordination, beginning at birth, facilitates the development of the infant's sense of agency, the expectation

of the ability to affect the partner. This sense of agency will be crucial during joint attention when infants attempt to influence the partner to join their own focus of attention.

Bigelow and Power (2016) investigated the effects of both maternal vocal and smiling contingency on infant social bids. Maternal smiling contingency was not as conducive to infant social bidding as maternal vocal contingency. However, when examining older infants at 4–5 months, Mcquaid et al. (2009) showed that maternal contingent smiling to infant smiles (within 1 s) in the baseline interactive phase of the Still Face Task predicted infant smiling social bids in the still-face phase. Maternal vocal contingency was not examined in this study.

Similarly, in another Still Face study with 5-month-old infants, Bigelow et al. (2017) found that maternal contingent mirroring (within-modality or cross-modal matching of infant behavior within 1 s with vocalization, facial expression, or gesture) was associated with infant social bidding during the still-face. Infants who experienced high maternal mirroring in the interactive phases showed greater infant social bidding in the still-face phase. These studies indicate that maternal contingent behaviors make significant contributions to infants' developing sense of agency.

Importantly, exploration of *infant contingency* (infants' contingent responses to maternal behaviors) in predicting social bids is lacking. The one exception is Mcquaid et al. (2009), who found that infant contingent smiling to mothers' smiles in the initial interactive phase was unrelated to infant smiling social bids in the still-face phase. A more thorough examination of the relation between infants' contingent responsiveness and their social bidding in the absence of maternal behavior awaits future research.

That social bidding, demonstrating infant agency, is relevant to infant capacities in joint attention was shown in the Striano and Rochat (1999) study with older infants (7 and 10 months). More infant social bidding in the still-face phase predicted greater competence in triadic joint engagement tasks. These results show that infant dyadic social initiative and triadic capacities are related. Striano and Rochat (1999, p. 560) note that their results imply "a somewhat more gradual process of social cognitive developments than that implied by a suddenly emerging '9-month revolution,'" which is favored by Tomasello (1999).

FUTURE RESEARCH DIRECTIONS FOR EXPLORING THE CONTINUITY OF PRIMARY AND SECONDARY INTERSUBJECTIVITY

We have argued that there is continuity between primary and secondary intersubjectivity and that both are necessary for the emergence of words. Infants share a full range of attention and emotion with their caregivers dyadically during their early months. Toward the end of the first year, they share attention triadically to objects in their immediate environment, which culminates in word acquisition.

To be sure, the cognitive and social requirements for word learning go beyond the achievements of intersubjectivity. Infants' further development of symbolic capacity, of which words are only one example, are also necessary as are neural and motor developments (Deacon, 1997). Everett (2017) describes various cognitive and cultural influences that make language possible.

Although research tracking the continuity of primary and secondary intersubjectivity is impressive, there are important gaps in the literature that should be addressed. First, longitudinal research is needed that follows early infant–adult interactions from primary intersubjectivity through to secondary intersubjectivity and ultimately to the acquisition of words. That research should evaluate how maternal behavior in early dyadic interactions with infants influences the subsequent development of joint attention. Importantly, studies documenting the role of infants in this development from primary to secondary intersubjectivity are sorely needed. Studies of the infant's role in the continuum from dyadic to triadic interactions, or the infant capacities necessary for triadic interactions, are scarce. Studies that examine how infant behaviors in early face-to-face interactions affect their later joint attention behaviors should be the focus of future work.

Second, most of the studies inferring the continuity of primary and secondary intersubjectivity have been correlational. Although longitudinal studies show associations between early maternal contingent behavior and later infant joint attention behaviors (Legerstee et al., 2007; Bigelow et al., 2010), experimental studies are needed. Such studies are likely to be intervention studies or studies that include infants with impairments of key abilities important to intersubjectivity, for example, infants with perceptual deficits, such as blindness or deafness (e.g., Bigelow, 2003; Depowski et al., 2015) or autistic children in whom the ability to engage with others is compromised (Cassel et al., 2007; Wan et al., 2013).

Third, more cross-cultural studies on intersubjectivity are needed. Most of the studies concerning intersubjectivity have been conducted in Western societies, where distal parenting practices focus on face-to-face interactions and object play. However, many non-Western societies have proximal parenting practices that emphasize physical contact and body stimulation. Some cross-cultural studies show that maternal responsiveness is similar in distal and proximal parenting cultures, although manifested differently (Keller et al., 2004; Keller, 2007; Kärtner et al., 2008, 2010). Mothers in distal parenting cultures are more likely to be verbally responsive to their infants, whereas mothers in proximal parenting cultures tend to use physical contact responses.

Interestingly, the mode of maternal responsiveness between distal and proximal parenting cultures diverges around the infant age of 2 months (Kärtner et al., 2008, 2010), when infants' perceptual-motor abilities increase their capacities for social engagement. Mothers from distal parenting cultures tend to reduce tactile responses to infants between 2 and 3 months and increase face-to-face interactions with facial and vocal responses, whereas mothers in proximal parenting cultures tend to continue to use high levels of tactile responsiveness (Kärtner et al., 2008, 2010). Although infant biological maturation is

universal and infants are predisposed to engage with others, biological predispositions interact with parenting practices early in life and adapt to cultural demands. Thus, we need research on how culture affects infant development from primary to secondary intersubjectivity.

WHY THE EMERGENCE OF WORDS IS UNIQUE IN HUMANS

The title of this article, "Intersubjectivity and the Emergence of Words," implies that words are well defined. Remarkably, psychologists and linguists have yet to agree about a definition of a word. In fact, that issue has rarely been considered.

The absence of a clear definition has led to many ambiguities about the type of utterances that count as words. Chomsky, for example, thinks that origin of words is a mystery: "The minimal meaning-bearing elements of human languages…are radically different from anything known in animal communication systems. Their origin is entirely obscure, posing a serious problem for the evolution of human cognitive capacities, particularly language" (Berwick and Chomsky, 2016, p. 90–91).

Some scholars have argued that words are not uniquely human. In a widely cited article, Hauser et al. (2002) distinguished two "faculties of language": a broad faculty that includes, among other abilities, words and concepts, and a narrow faculty that includes grammar. In that framework, they concluded that only the narrow faculty is uniquely human.

We agree that the use of grammar is uniquely human. But here, we define words in a way that warrants their inclusion in the narrow faculty of language, a faculty that is uniquely human. We define words functionally, as arbitrary symbols that are used conversationally, that is, declaratively. Their function is to transmit information socially by referring to particular objects, activities, or their attributes. Later in development, words can also refer to internal states. This definition implies that only humans use words. It also recognizes the social origins of words.

Our definition of a word differs from that of many scholars who study the communicative abilities of animals. As evidence that animals use words, they cite the communicative abilities of chimpanzees, monkeys, dolphins, dogs, and birds (Savage-Rumbaugh et al., 1993; Hauser et al., 2002; Kaminski et al., 2004; Seyfarth et al., 2005; Pepperberg, 2016). It is important to note that none of those studies defined words.

Another problem is the distinction between comprehension and production. Studies of comprehension cannot provide a definitive answer to the question of whether animals use words because it is not clear if a subject's response to an experimenter's vocal command is based on the perception of its acoustic properties or its lexical status. That problem arises both in instances of individual commands (e.g., dogs, Kaminski et al., 2004) and in sequences of words (e.g., chimpanzees, Savage-Rumbaugh et al., 1993).

Studies of production often fail to distinguish between declarative and imperative functions of communication. Regarding chimpanzees, Berwick and Chomsky (2016, p. 148) cited the ability of Nim, a chimpanzee trained by Terrace et al. (1979) to produce words. It is true that apes can be trained to use sign language or arbitrary visual symbols to communicate (Gardner and Gardner, 1969; Premack, 1971; Rumbaugh, 1977; Terrace et al., 1979; Savage-Rumbaugh, 1994). In criticizing claims that those studies provide evidence that apes use words, however, Terrace (2019) argued that the responses in question only served an imperative function of obtaining specific rewards.

Imperatives are responses to satisfy a need, whereas declaratives are responses that refer to objects in a conversational manner. The following example illustrates the difference between utterances of apes and humans: an imperative in the case of the former, a declarative in the case of the latter. Having been shown a dog or a picture of a dog, the ape might sign *dog*, or touch a lexigram meaning *dog*, in order to obtain food or drink. The sight of a dog was simply a cue for making a response to obtain a physical reward. By contrast, if an infant sees a dog or a picture of a dog, she might utter *dog*, in response to which her caretaker responds socially, typically, with other words, for example, *nice dog*, *big dog*, *no that's a cat*, and so on.

In discussing differences between the utterances of apes and humans, Terrace (1985) noted that the utterances of human infants are spontaneous and bi-directional, whereas ape utterances are neither. Most important is an ape's inability to name or refer to objects in a declarative way.

In humans, utterances that produce primary rewards (imperatives), like a morsel of food, make up a miniscule portion of their vocabulary. If, as with apes, such utterances were the only ones a human could learn, language would never develop. From the beginning of word acquisition, the vast majority of human utterances are declaratives.

In any of the thousands of extant human languages, the number of declarative words is unlimited. It is always possible to conceive of a new word to name a particular object, action, or attribute. It is that feature that allowed our ancestors to refer to objects that were not immediately present, to past and future events, and to imaginary objects. In short, the transition from animal communication to declarative words marked the beginning of verbal culture. That transition took place because of the development of intersubjectivity.

EVOLUTION OF INTERSUBJECTIVITY

From birth, infants embark on a trajectory of primary and secondary intersubjective engagements with their caretakers that are uniquely human. How did such interpersonal relations evolve? In particular, from what aspects of our ancestors' behavior did a high degree of social coordination and cooperation, both crucial features of intersubjectivity, evolve? To answer that question, we need to identify the selection pressures that favored increases in social communication and intention-reading.

Looking at chimpanzees, our closest living ancestors, infant–mother relations differ profoundly from those of humans. Although some features of intersubjectivity, for example, mutual eye gaze, have been observed in chimpanzees, they are

short-lived and disappear when infants are a few weeks old (Bard, 2011). As noted by Oller et al. (2019), ape mothers "do not respond to infant vocalizations with vocalizations of their own, and rarely if ever vocalize independently to their infants."

According to Hrdy (2009), the evolutionary origins of intersubjectivity can be found in the difference in child-rearing practices in apes and humans. Chimpanzee mothers do not allow other members of their group access to their infants for approximately 6 months. For gorillas and orangutans, that period is longer.

By contrast, human infants are reared by cooperative child-rearing, a practice in which a mother's care of her infant is supplemented by members of her immediate family, so-called "alloparents." The mother is still the primary source of care but sisters, brothers, aunts, fathers, and grandmothers, even non-kin, also share in caring for newborn human infants.

To survive, infants have to rely not only on their mothers, but also on their alloparents. Thus, human infants have to learn to assess the emotions and intentions of alloparents, as well as those of the mother. They begin to do that right after birth. By contrast, infant apes rely only on their mothers.

There is compelling evidence that cooperative child-rearing was practiced by *Homo erectus*, a human ancestor who evolved about 1.8 million years ago (O'Connell et al., 1999). It is likely that *Homo erectus* infants, and their multiple caregivers, were socially involved in ways that apes never were. *Homo erectus* infants had to learn to interpret not only their mothers' engagement but also the moods and intentions of alloparents who might help.

How best to attract care under such circumstances? Hrdy (2009) argues by engaging socially with a caregiver, by crying, smiling, vocalizing, or gesturing. Those infants who were best at engaging in the non-verbal communication that defines intersubjectivity would be the best cared for. Such novel selection pressures favor a very different type of ancestor, one that Hrdy refers to as "emotionally modern." They were, as Hobson (2002) noted in the epigraph, mothers and alloparents who could share attention and emotions with their infants, and infants who could reciprocally communicate their attention and emotions.

Hrdy also notes that human ancestors were emotionally modern before they became anatomically or cognitively modern: "Long before the emergence of *anatomically modern* big-brained humans…, or before…symbolic thought and language, these emotionally different apes [actually *Homo erectus*] were already eager to appeal to and help others" (Hrdy and Burkart, 2020, p. 8, italics in original).

Recent research also suggests the altricial nature of *Homo erectus*. The birth canal of *Homo erectus* had narrowed to the point at which, like humans, the size of an infant's brain at birth was relatively small (Simpson et al., 2008; Gruss and Schmitt, 2015). That suggests that, like modern human infants, newborn *Homo erectus* infants required long-term caretaking in order to survive, thus characterizing them as altricial.

Locke and Bogin (2006) and Oller and Griebel (2021) hypothesized that, as a result of their altricial needs, there was intense pressure for *Homo erectus* infants to provide fitness signals to their caregivers for long-term nurturance and protection. Specifically, they hypothesized that vocalization, expressed as protophones, satisfied that pressure. Oller and Griebel (2021, p. 8) conjectured that "relative altriciality and cooperative breeding may have co-evolved, with both supplying selective pressure and vocal fitness signaling in the hominin [Homo] case."

Hrdy's and Tomasello's Views of the Evolution of Intersubjectivity

In this context, it is important to note differences between Hrdy's and Tomasello's approaches to intersubjectivity. Tomasello argues that the cognitive differences between chimpanzees and humans stem from the type of tasks on which those differences are evaluated. When the task is competitive, chimpanzees are able to read another's intentional stance as well as humans. It is only in cooperative tasks in which chimpanzees and humans differ.

In contrast to Tomasello, and in agreement with Hrdy, we would argue that the difference is more fundamental. The competitive task obscures the actual difference because it does not take into account differences in intersubjectivity in humans and chimpanzees. The chimpanzee's ability to read another's intentional stance differs from the human's ability to share intentions and communicate about them in a bi-directional fashion.

Moreover, Tomasello did not specify the origins of a high degree of social coordination and cooperation in humans. In his "interdependence hypothesis," Tomasello et al. (2012) maintained that shared intentionality in humans is an adaptation mainly for *adults*' uniquely cooperative forms of social life. Only recently, however, did Tomasello acknowledge Hrdy's view that cooperative breeding was key in an infant's ability to solicit care and attention and to develop shared intentionality (Tomasello and Gonzalez-Cabrera, 2017; Tomasello, 2020).

CONCLUSION

Beginning with emotionally modern ancestors, in whom it is likely that intersubjectivity first developed, there was a remarkable transition in communication. The shift from a limited number of uni-directional emotional signals, which many animals share with humans, to intersubjectivity, was a shift to bi-directional, moment-by-moment emotional and cognitive communication that starts at birth. Such reciprocally contingent communication is crucial for the emergence of words.

Research on interactions in *early infancy*, particularly the key role of contingency in mother–infant prelinguistic communication, shows that an infant's progress toward joint attention and word learning, rather than being a product of a 9-month revolution, begins at birth and is an incremental process of infant social development to which both mother and infant contribute.

Early bi-directional communication between infant and caregiver is facilitated by maternal scaffolding of infant communicative abilities. It culminates with joint attention and

the emergence of words, which ultimately generates an indeterminately large number of voluntary and arbitrary symbols. That is the basis for grammar, a complex topic that lies outside the scope this article.

The evolution of words could not have occurred without primary intersubjectivity. The emotional communication that an infant experiences with her caregiver from the beginning of life is foundational for the emergence of words.

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HT, AB, and BB contributed equally to the writing of the article and approved the submitted version.

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Rhythmic Relating: Bidirectional Support for Social Timing in Autism Therapies

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We propose *Rhythmic Relating* for autism: a system of supports for friends, therapists, parents, and educators; a system which aims to augment bidirectional communication and complement existing therapeutic approaches. We begin by summarizing the developmental significance of *social timing* and the *social-motor-synchrony* challenges observed in early autism. Meta-analyses conclude the early primacy of such challenges, yet cite the lack of focused therapies. We identify core relational parameters in support of social-motor-synchrony and systematize these using the *communicative musicality* constructs: *pulse*; *quality*; and *narrative*. *Rhythmic Relating* aims to augment the clarity, contiguity, and pulse-beat of spontaneous behavior by recruiting rhythmic supports (cues, accents, turbulence) and relatable vitality; facilitating the predictive flow and just-ahead-in-time planning needed for good-enough social timing. From here, we describe possibilities for playful therapeutic interaction, small-step co-regulation, and layered sensorimotor integration. Lastly, we include several clinical case examples demonstrating the use of *Rhythmic Relating* within four different therapeutic approaches (Dance Movement Therapy, Improvisational Music Therapy, Play Therapy, and Musical Interaction Therapy). These clinical case examples are introduced here and several more are included in the **Supplementary Material** (Examples of Rhythmic Relating

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in Practice). A suite of pilot intervention studies is proposed to assess the efficacy of combining *Rhythmic Relating* with different therapeutic approaches in playful work with individuals with autism. Further experimental hypotheses are outlined, designed to clarify the significance of certain key features of the *Rhythmic Relating* approach.

Keywords: autism, Rhythmic Relating, synchrony, sensorimotor integration, therapy, social timing, movement, Communicative Musicality

INTRODUCTION

Co-regulation: A Paradox at the Heart of Autism[1]

Some people with autism experience their authentic self as non-social. Here at the start, we wish to draw attention to the rights of the individual with autism to remain incommunicado and socially withdrawn. Can we, as people without autism, be okay with this? Some people with autism live with a longing to interact, so often denied or limited by the anxiety of sensory overwhelm and fracture.[1] Can we be available but truly not demanding? With these terms comprising our ethical baseline, we aim to develop a system of relational skills for neurotypical communicators based on the needs, concerns, and specific sociabilities of people with autism.

For many people with autism the social world can be painful, fractured, overwhelming, and compulsive. Paradoxically though, the need to learn how to self-regulate and self-integrate often necessitates some level of *co-regulation* – a social phenomenon[2].

From birth, typically-developing (TD) infants actively seek signals and experiences of safety from others (Porges, 2018); they are seeking regulation through shared experience (co-regulation), where *regulation* can be defined as: the ability to attain and maintain a *good-enough* (appropriate) state of arousal[3] fit for task/environment/moment. Without safety and co-regulation, all infants become dysregulated. This can appear in behavior as over/under vigilance and response, fight/flight, agitation, shut down, avoidance, or seeking sensory stimulation/information.

Co-regulation is only possible when people feel safe together. Safety sets off a train of events. Initially, the nervous system either down-regulates the Mobilization response (fight/flight) or re-routes the Immobilization response (shut down/freeze) (ibid.). In either case, the next step activates the Social Engagement System, supporting ease and sociability (Porges et al., 1996; Porges, 2018). This is the basis of co-regulation: initial safety = social engagement increases = more safety = more engagement = . . .

Along with physical touch within the earliest attachment relationship, TD infant-parent *play* is a fundamental domain of co-regulation. During play, TD infants push the boundaries of safety, expanding the window through forays in and out of vulnerability – think of the uncertainty inherent in the games "hide-n-seek" and "peek-a-boo." For co-regulation, what is important is the sense of traveling safely together through a familiar-enough narrative flow of play, from calm through to vulnerable and back again (Schore, 1994; Porges et al., 1996; Porges, 2021; Porges and Daniel, 2021). This co-regulatory play process is seen as an exercise for self-regulation and self-integration (Porges, 2021).

That sense of co-regulatory traveling together necessitates good-enough social timing. Yet, to differing degrees, individuals with autism often find themselves out of sync with other people. Children with autism have difficulty picking up subtleties of gesture from TD children (Rochat et al., 2013; Di Cesare et al., 2017a). TD adults have difficulty picking up subtleties of gesture from children with autism (Casartelli et al., 2020b). This bidirectional range of perceptual and motoric dissimilarity can lead to mutual misunderstanding. Asymmetries and asynchronies in the meeting of two people can lead to a mismatch in time-frame; the result: it is difficult to play together.

If we can tailor our communication toward social timing and safety, we may facilitate a gentle vagal feedback loop within the person with autism. Initial simplicity, sameness, and tailored communication may support a sense of safety, just a little. . . which will reduce anxiety and increase interactivity, just a little. . . which may lead to a short moment of interactive flow. . . which will reduce anxiety and increase interactivity, just a little. . .

Yet some children or individuals with autism may not be *ready* to interact. People with autism often have baseline sensory integration (SI) challenges (Ben-Sasson et al., 2019), including overwhelm or under-discrimination in tactile, visual, auditory, proprioceptive, and/or interoceptive fields. These challenges are neurosequentially primary to social engagement, leading to a primary feeling of wrongness, unsafety, and dysregulation. Here, any attempts at interaction may result in further withdrawal – a response to sensorimotor demand, SI challenge, or emotional overwhelm. Clearly, any support for playful co-regulation needs to address challenges of SI (Ben-Sasson et al., 2019), *as well as* those of Social Timing (Wimpory et al., 2002), and will often start by addressing the need for acclimatization, aloneness, simplicity, sameness, calm, short duration interaction, and rest. We suggest a fundamentally client-led basis to interactive play. This counteracts the potential ontological risk of coercing any child or individual with autism into neurotypical expectations for patterns of social engagement.

[1]Written in dialogue with Penelope 'Pum' Dunbar. Pum is an artist and creative researcher/thinker with autism (Delafield-Butt et al., 2021a,b).

[2]Here we are suggesting that the primary route to self-regulation, especially for infants, is through physical and social co-regulation with another person. There are other routes, for instance: co-regulation with a calming animal; sensitive physical containment; taught techniques (such as breath work); rhythmical physicality etc. All of which may serve as powerful potential supports for individuals with autism.

[3]Arousal, *the state of behavioral or physiologic activation*. https://medical-dictionary.thefreedictionary.com/arousal - accessed 10/11/2021. We note that the term *arousal* can have either negative or positive connotations. When used throughout this text, we will clarify with the terms: *Social Engagement System* arousal (positive) or *Mobilization System (Fight/Flight)* arousal (defensive/negative).

Rhythmic Relating for Autism

In this paper we propose *Rhythmic Relating*, a system which aims to augment bidirectional communication and facilitate good-enough social timing; opening up the possibility of playful therapeutic interaction, small-step co-regulation, and layered sensorimotor integration. Our intention, in researching the model, was to take a fresh look at the current neuroscience and experimental psychology of rhythm, musical experience, movement, interaction, and autism. We wanted first, to be surprised by new parameters and then systematize these parameters as a working therapeutic tool-kit using solid concepts and practitioner experience from best-practice therapy (Dance Movement Therapy, Improvisational Music Therapy, Play Therapy, and Musical Interaction Therapy) and the *Communicative Musicality* model.

Rhythmic Relating focuses on interaction between neurotypical people and clients with *Autism with Therapeutic Needs* – Autism$^{(TherapeuticNeeds)}$. By this, we mean individuals with a classical autism phenotype[4], and with *therapeutic needs which cause distress*[5] (mental health, SI, and/or dysregulation); perhaps with co-morbid learning disability (LD); perhaps non-speakers or unconventional communicators.

Rhythmic Relating is not a stand-alone model. It can complement any therapeutic approach open to elements of person-led practice. We assume a sensitive, playful practitioner[6] working with a single client[7]. This could be within a group setting, but we focus on one-to-one moments of interaction. We assume practitioners will be prepared to use their body and voice, but will not (necessarily) have expertise in singing, music, or with any particular instrument.

Communicative Musicality, Social Timing, and the Kinetic Melody of Play

Playful human interaction has been described as *kinetic melody* (Luria, 1973), as a *dance unfolding* (Stern, 2010), in terms of *primary intersubjectivity* (Trevarthen, 1998; Trevarthen and Delafield-Butt, 2017a) or *Communicative Musicality* (Malloch and Trevarthen, 2009). Neurotypical infant play is an unfolding, real-time, micro-timed orchestration of communicative acts (of movement, sound, and intention). This necessitates a mode of social timing in which both players *continuously communicate near-future states* and *plan communicative acts just-ahead-in-time*.

For us, dynamic *social timing* represents temporal aspects of the 'dance' of interaction (Wimpory et al., 2002). It involves intra- and inter-personal levels of cross-modal expression, processing and comprehension that support a deep feeling of connection. Social timing is a key factor in the embodied dynamics of *primary intersubjectivity* (Trevarthen, 1998) defined here as: *the early patterns of affective relating, enabling the sharing of intentions and interest for learning and growth* (Trevarthen, 1998; Trevarthen and Delafield-Butt, 2017a). These patterns are inherently rhythmical. Humans share a pre-position to perceive, move, and interact in temporal, rhythmic ways (Papoušek, 1996; Trevarthen, 1999; Osborne, 2009). There is rhythmicity in the real-time interface between the human body in motion, the neurotypical organization of motor acts, the pattern and impulse generation of biological clocks, and human relational dynamics (Papoušek, 1996; Trevarthen, 1999; Osborne, 2009).

At the heart of intersubjective regulation, embodied rhythmicity enables the coupling of information within, and between, the pre-motor cortices and certain sub-cortical bodies which energize the feeling tones of intentional acts (brain stem, basal ganglia, and limbic structures) (O'Rahilly and Müller, 1994; Holstege et al., 1997; Trevarthen, 1999; Grahn and Brett, 2007; Rizzolatti et al., 2014). "The movement-creating reticular networks and nuclei are intricately combined with the neurochemical systems of emotion. The same activating neurones that select movements and control their energy and smoothness also cause changes in the emotions felt, and the intensity and 'color' of consciousness" (Trevarthen, 1999, p. 161). Rhythmicity modulates our movements and colors them with the feeling of momentum, emotion and purpose. It modulates coherent whole-body transformations, enabling the body to express intentions *as one system*. Rhythmicity, "... expresses an integral stream of events created in the whole brain, which conduct separate body parts to targets... synchronizing moves so the effects of separate actions can balance one another and form anticipated sequences and coincidences in space and time, as nearly faultlessly as possible. The gracefulness of all we do depends on it" (Trevarthen, 1999, p. 160).

Social timing encompasses both individual motor timing (intra-personal sensorimotor integration) and social-motor-synchrony (SMS) (temporal alignment of the perceptions, predictions, and motor behavior of two or more people) (Wimpory et al., 2002; Fitzpatrick et al., 2016). SMS relies on predictions generated within the rhythmic flow of interaction and, in turn, enables the furthering of those rhythms. The rhythm of interaction occasionally falls into direct sync, more often feels like two complementary players sharing different parts yet following the same time-frame, and often falls out of sync entirely – needing repair (see section "Good-Enough Social Timing and Learning through Repair" below) (Feldman and Eidelman, 2004; Feldman, 2007a,b).

Through the parameters of Communicative Musicality – *pulse*, *quality*, and *narrative* – we can describe the rhythmic flow of play and come to understand how this flow facilitates the anticipation of an other's near-future actions, and supports the just-ahead-in-time organization of action with intent (Malloch and Trevarthen, 2009).

Pulse is described both in terms of neurobiological time-keeping (the pattern generation of biological oscillators with regularity and momentum) *and* in terms of the related behavior produced: "pulse is the regular succession of discrete behavioral

[4]*Autistic Disorder/Childhood/Infantile Autism* (ICD-10 6A02: World Health Organization, 1993); *Autistic Disorder now included within ASD (ICD-11 6A02:* World Health Organization, 2019*)*.

[5]Our clarifying term, Autism$^{(TherapeuticNeeds)}$, relates closely to the DSM V (American Psychiatric Association, 2013) qualifier: level 3, i.e., "requiring very substantial support."

[6]We use the term 'practitioner' to include anyone working with the Rhythmic Relating approach.

[7]We use the age-non-specific term "client," to refer to anyone for whom Rhythmic Relating is developmentally and therapeutically appropriate.

steps through time, representing the "future-creating" process by which a person may anticipate what might happen and when" (Malloch, 2017, p. 65).

Quality refers to, "... modulated contours of expression moving through time. These contours can consist of psychoacoustic attributes of vocalizations – timbre, pitch, volume – and/or attributes of direction and intensity of the moving body" (Malloch and Trevarthen, 2009), akin to what Stern named *vitality affects*[8].

Narrative refers to the story-arcs through which we travel together in play, from birth onward, composed in non-verbal rhythms and contours of voice and movement (Malloch and Trevarthen, 2009; Trevarthen and Delafield-Butt, 2013b; Delafield-Butt and Trevarthen, 2015). Each narrative arc is co-created between players, as they share and develop expressive acts, and often follows a flow through discernable stages: Introduction; Development; Climax; Resolution (Malloch and Trevarthen, 2009; Trevarthen and Delafield-Butt, 2013b). The narrative arc helps us get a feel for the flowing build-up of play. Co-regulation is enabled when players travel together in good-enough synchrony through familiar-enough narrative arcs of a particular quality (i.e., flowing in an out of anticipation, vulnerability, and calm) (Schore, 1994; Porges et al., 1996; Porges, 2021; Porges and Daniel, 2021). In emphasis, here we will use the term *co-regulatory narrative arc* as defined by the following model (slightly adjusted from Brazelton et al., 1974): (Re)Orientation; Development; Peak; Conclusion; Proactive Withdrawal (**Figure 1**). The concept of the narrative arc as a co-regulatory, therapeutic experience has been tested, for work with individuals with autism, within Intensive Interaction (Delafield-Butt et al., 2020), Play Therapy (Daniel, 2019), and Developmental Movement (Daniel, 2017).

Critical to Rhythmic Relating will be the sensitive layering of individually tailored sensory combinations. Different clients are likely to benefit from the parameters of communicative musicality being facilitated in different sensory ways. Importantly then, *pulse*, *quality,* and *narrative* are reported as experientially *amodal* (beyond modal) (Malloch and Trevarthen, 2009). They communicate the *patterned essence* of dynamic happenings, and that essence can be experienced, communicated, and perceived *via any* sensory modality or combination.

PREDICTION, SOCIAL TIMING, INDIVIDUAL MOTOR PLANNING, AND SOCIAL MOTOR SYNCHRONY IN EARLY AUTISM

Autism and Synchrony

Positive measures of synchrony in TD *preverbal interaction* provide developmental correlates for the onset of later interactive, cognitive, and symbolic functions (reviewed by Leclère et al., 2014; Feldman, 2017, 2020; Bell, 2020; and by Wimpory, 2015, regarding the implications for autism). These developmental functions include: later interactive synchrony (at 9 months and 2 years, Feldman et al., 1996); symbolic functioning/social pretense (Harrist et al., 1994; Feldman and Greenbaum, 1997); social-emotional adaptation (Feldman and Eidelman, 2004); empathy (reviewed by Feldman, 2017) and the brain basis of affect-specific empathy (Yaniv et al., 2021); and, later acquisition of language skills (Rohlfing and Nomikou, 2014).

The same developmental functions, when disrupted, are core areas of disability in autism: interactive synchrony (Feldstein et al., 1982; including turn-taking, Lee and Schertz, 2020); symbolic functioning/social pretense (Hobson et al., 2009; Varga, 2011); social-emotional adaptation (Tse et al., 2021); empathy (Koehne et al., 2016; Song et al., 2019; plus careful critical consideration via: Fletcher-Watson and Bird, 2020); later acquisition of language skills (Luyster et al., 2008*)[9], including pragmatics (overview: Lim, 2018).

Children and adolescents with autism (including high functioning autism, HFA) display reduced or atypical synchrony in conditions rating both *individual motor timing* and SMS (meta-analyses: Baldwin et al., 2021; McNaughton and Redcay, 2020*).

Individual motor timing difficulties in autism (including HFA) involve increased *variability* in individual motor output (Gowen and Hamilton, 2013; Kindregan et al., 2015; Kaur et al., 2018), increased *sensorimotor "noise"* disrupting perceptuomotor integration (Gowen and Hamilton, 2013), and *poor temporal integration of sensorimotor information for efficient prospective motor organization and planning* (Cattaneo et al., 2007; Gowen and Hamilton, 2013; Kaur et al., 2018; Su et al., 2020). It is highly likely these local disturbances in individual motor timing *precipitate* SMS disruption (Mottron et al., 2003; Fitzpatrick et al., 2016; Nebel et al., 2016; Su et al., 2020; meta-analysis: Bloch et al., 2019; conceptual perspective: Trevarthen and Delafield-Butt, 2013a; cognitive implications: Cook, 2016).

For autism-neurotypical interaction, bidirectional SMS appears challenged by these individual motor timing disturbances, principally in terms of the complex *temporal organization* needed for *interactive synchronization* (coupling pendulum task, Fitzpatrick et al., 2016; marching and clapping, Kaur et al., 2018; reach-to-grasp, Su et al., 2020). Interestingly, within these simple-parameter tasks (ibid.), *gross* motor deficit or basic delay in information transmission do not appear to be significant. Although, within the dance of interaction, these movement variability factors can exacerbate differences in expressive quality between individuals with autism and those

[8]The *vitality affect* of movement refers to an integrated perceptual, affective and expressive experience: the felt experience of an intentional flow of action combining movement, force, and direction altogether with intention and feeling (Stern, 1999, 2010).

[9]Throughout this paper, a citation date with a superscript * (e.g., Jones, 2019*) denotes any autism-specific study or meta-analysis in which cognitive level(s) are unspecified and/or where LD may be a confounding variable. Such studies, and their inclusion with an asterisk here, reflect changing emphases in research priorities over time. Autism-specific studies which are controlled for LD and/or other neurodevelopmental concerns (for instance, though the inclusion of a cognitively matched control group, the removal of certain subjects from the design, or through employing, observing, or discussing only subjects with High Functioning Autism), we leave without a superscript. Autism-related hypothesis/theory articles and non-autism specific studies and articles, we also leave without a superscript.

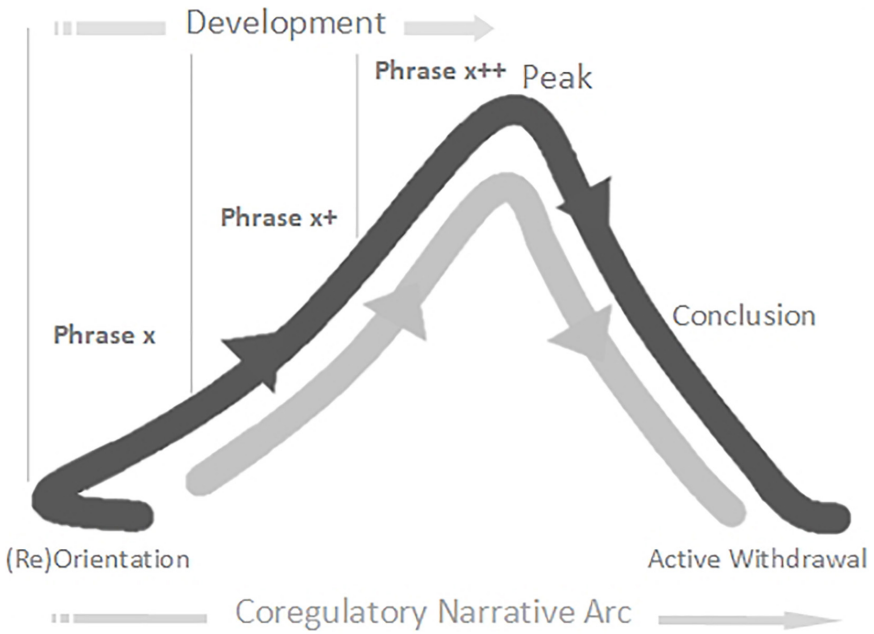

FIGURE 1 | The *Co-regulatory Narrative Arc* of early playful interaction in typical development.

without (Gallese and Rochat, 2018; Casartelli et al., 2020a,b), creating dissonance or intersubjective incongruence (Trevarthen et al., 2006; Trevarthen and Delafield-Butt, 2013a, 2019). The degree of SMS disruption evidenced in autism-neurotypical interactions correlates significantly with severity of autism diagnosis (Nebel et al., 2016; Kaur et al., 2018; Su et al., 2020; Overview McNaughton and Redcay, 2020*).

Where parents naturally achieve greater early synchrony with their autistic child with learning disability, this has been found to predict positive child communication outcomes up to 16 years later (Siller and Sigman, 2002, 2008). There is a slowly growing body of empirical evidence suggesting that effective targeting of temporal synchrony is a mediating factor within varied therapeutic interventions with young children with autism (with, and without LD) (Wimpory et al., 1995, 2007; Landa et al., 2011; Pickles et al., 2015; Srinivasan et al., 2015; Dvir et al., 2020; Forti et al., 2020; Griffioen et al., 2020; Whitehouse et al., 2021). Meta-analyses conclude the early primacy of synchrony challenges in autism (including HFA), yet cite the lack of focused therapies (Bloch et al., 2019; McNaughton and Redcay, 2020*; Baldwin et al., 2021).

Clock Genes and Their Possible Influence in Autism

Timing genes, with multi-level influences across various tides of biological time from circadian rhythms to high-frequency oscillators, are indicated in several genetic studies of autism (usually with co-morbid LD: Wimpory et al., 2002; Nicholas et al., 2007; Nguyen et al., 2010; Neale et al., 2012; Bowton et al., 2014; Yang et al., 2016; Briuglia et al., 2021). It is noteworthy that circadian-associated clock genes can be multifunctional, operating in systems and gene pathways additional to driving the circadian rhythm. For example, the autism-associated clock gene, *RORA* (Nguyen et al., 2010*), harbors causative mutations in certain individuals with HFA or autism plus mild LD (Guissart et al., 2018). This gene is also essential for normal cerebellum development and typical movement (Dussault et al., 1998) and for the development of murine primary somatosensory maps (Vitalis et al., 2018). The role of the clock gene, *per*, in modulating high frequency oscillators in *Drosophila,* concerned with fine motor control and social timing (Kyriacou and Hall, 1980; Beaver and Giebultowicz, 2004), together with findings of genetic association of *PER1* with autism, with and without LD (Nicholas et al., 2007; Neale et al., 2012; Yang et al., 2016), strengthens the notion that clock genes contribute to temporal deficits in autism.

Autism and Auditory-Temporal Processing

Individuals with autism often display altered auditory temporal processing, including: difficulties detecting duration changes among auditory stimuli (Lepisto et al., 2006); atypical responses to the temporal structure of discrete auditory stimuli (Lepisto et al., 2005, 2006); prolonged latency in unmodulated acoustic startle response (ASR) (Ornitz et al., 1993*); difficulties discriminating timing information between sequential auditory stimuli (Kwakye et al., 2011); delayed latency of evoked potentials in superior temporal gyrus in response to tones of various pitch (Roberts et al., 2010); and difficulties in reproducing auditory stimuli of standardized duration (Szelag et al., 2004).

It is possible that, not only is the neural response to timing information in auditory stimuli atypical for many people with autism, but the timing of the brain's response itself is *delayed*

in response to auditory input (Oram Cardy et al., 2005; Kwakye et al., 2011). These delays may result in a decrease in signal-to-noise ratio of neural signaling for auditory cues, resulting in the autistic experience of sensorimotor "noise" (Brincker and Torres, 2013*; Gowen and Hamilton, 2013) and disturbed time-locking of neural response to discrete sensory events (see Rubenstein and Merzenich's, 2003, theoretical account). Russo et al. (2009) have demonstrated that the Event Related Potential (ERP) response to auditory speech stimuli, in the absence of background noise, for children with HFA is similar to that *with* background noise for children with TD. This suggests that there may be a degraded response to auditory stimuli at baseline in ASD (Kwakye et al., 2011).

Autism, Movement Control and Variance

Motoric anomalies in autism (distinct from LD and TD) have been detected at between 3 and 5 months (Esposito et al., 2009) and by approximately 1 year for gait differences (Esposito and Venuti, 2008; Esposito et al., 2011). Subsequent proof-of-concept longitudinal research using wearable sensors has identified reduced motor complexity from as young as 3 months of age and at each 3-monthly time point studied, in two of five genetically high-risk infants later assessed (Wilson et al., 2021). These two infants were the only ones who received a subsequent diagnosis of ASD. Furthermore, the correlation, between motion complexity and ASD-outcome, was stronger than the correlations between motion complexity and outcomes pertaining to adaptive skills and cognitive ability (ibid.).

There are several brain regions involved in pre-motor and motor control which are implicated in autism studies: cortical pre-motor areas [pre-SMA (Puzzo et al., 2010), pre-motor cortex (Silk et al., 2006; Puzzo et al., 2010)], and subcortical areas [basal ganglia (Nayate et al., 2005; Rinehart et al., 2006; Qiu et al., 2010; Estes et al., 2011), brainstem (review: Delafield-Butt and Trevarthen, 2017)]; and cerebellum (review: Courchesne et al., 1994; Akshoomoff et al., 2002; Nayate et al., 2005; Rinehart et al., 2006; Mosconi et al., 2015).

Autism and Prospective (Just-Ahead-in-Time) Motor Planning

Children with autism often display disrupted prospective motor organization of intentional movement (Mari et al., 2003; Rinehart et al., 2006*; Cattaneo et al., 2007; Fabbri-Destro et al., 2009; Chua et al., 2021). Such "autism motor signatures" can be computationally identified from 2 ½ years of age (Anzulewicz et al., 2016*), and may be detectable from birth. Reduced prospective sensorimotor control of arm movements has been observed in prematurely born infants at-risk for neurodevelopmental disorders (Delafield-Butt et al., 2018). At 3–6 months old, as compared with TD infants, infants with autism showed significantly less anticipatory mouth opening in response to an approaching spoon at feeding times (Brisson et al., 2012*). A series of retrospective home-video studies have documented evidence that infants with autism (younger than 12 months) display a lack of organized anticipatory social behaviors (Adrien et al., 1991s*; Osterling and Dawson, 1994; Baranek, 1999*; Maestro et al., 2001; Trevarthen and Daniel, 2005; Brisson et al., 2014).

Moving with organized intent involves the just-ahead-in-time generation of a spatiotemporally coherent motor 'image', organized to achieve movement with efficient purpose (Lee, 2009). This prospective, intentional motor control is operative from before birth from the 2nd trimester (Delafield-Butt and Gangopadhyay, 2013). Its intentions first reach into the imminent future of just 1–2 s, but in human development this soon extends to enable goals that are many tens of seconds, minutes, even hours, days or years into the future (Trevarthen and Delafield-Butt, 2017b).

For people with autism, this essential motor image may be disrupted in space or time, due to disturbed temporal integration of multimodal information. For example, in a precision grip task, two *temporal* variables (load force onset latency and time to peak grip force) and two *force* variables were used to differentiate children with ASD and TD children (David et al., 2012). Children with ASD presented with significant motor coordination challenges *only* on the temporal variables. The researchers concluded, "... that subtle problems in the timing of motor actions, possibly related to maturational delays in anticipatory feed-forward mechanisms, may underlie some motor deficits reported in children with ASD" (ibid).

In a reach-to-grasp task, autistic individuals did not rhythmically coordinate the reaching of the arm and the opening of the fingers in a fluid intentional flow – instead they performed one act and *then* the other separately (Mari et al., 2003). In contrast, TD children coordinated intentional sequences of arm and hand actions fluently in "pre-reaching" and gesturing from early infancy, to achieve coherent goals distal in time and action space (von Hofsten, 1984).

Children with autism displayed motor impairment without any deficits in proprioception, during a simple elbow flex-extend task (Fuentes et al., 2011). These findings may indicate that proprioceptor sensors are neither hyper-, nor hypo-sensitive in individuals with autism, rather it may be that temporal integration of proprioceptive information with other sensory input is disturbed (ibid.).

Prospective movement involves the just-ahead-in-time arrangement of single motor acts into action-chains, organized with advance respect to the movement requirements of *the intended goal* (Fogassi et al., 2005; Bonini et al., 2011; Rizzolatti et al., 2014; Rizzolatti and Sinigaglia, 2016). Experiments with monkeys have demonstrated that single motor acts will be organized by markedly different pre-motor and parietal neuron activation, when this act is part of action-chains that have different *goals* [e.g., grasping food for eating (Chain A) vs. grasping food for placing (Chain B)] (Fogassi et al., 2005; Bonini et al., 2011). The first motor act in a functional chain is organized and tagged with regards to subsequent acts, this tag being the neural handle to instigate the whole action-chain. For instance, in Chain A, on activation of the initial motor act (reach-to-grasp), neurons will fire simultaneously which facilitate pre-emptory mouth opening. The same initial motor act (tagged differently in Chain B) will not pre-empt mouth opening.

Across various tasks, including a version of the above experiment adjusted to assess the Electromyography (EMG) activity of the mouth-opening MH muscle in human children, Cattaneo et al. (2007) demonstrated that goal-specific action-chaining exists for TD infants. While for children with autism, in the same tasks, goal-specific action-chaining is significantly impaired: "...for TD children, the EMG activity of the MH muscle started to increase several hundred milliseconds *before* the hand grasped the food. It continued to increase during actual grasping, and, as expected, it reached its peak when the individual started to open the mouth. The behavior of the MH muscle found in children with autism was strikingly different. In this group, no activity increase was found during the entire reaching and grasping phases. The muscle became active *only* during the bringing-to-the-mouth phase" (Cattaneo et al., 2007, p. 17827).

Moving in interactive synchrony with another person involves just-ahead-in-time understanding of their intention, which advance-informs the generation of our own spatiotemporally coherent motor image. Goal-oriented action-chaining, coupled with "action-constrained" mirror neuron activation on observation of another's initial motor act, plays a significant role in the anticipation of another's intention (Fogassi et al., 2005; Cattaneo et al., 2007). "By activating a specific action chain from its very outset, this mechanism allows the observer to have an internal copy of the whole action before its execution, thus enabling them to understand directly the agent's (*functional*) intention" (Cattaneo et al., 2007, p. 17825, italics added). TD infants experience the intentions of others experientially and as gestalts, *prior* to understanding them cognitively (Cattaneo et al., 2007). Children with ASD do not (Cattaneo et al., 2007; Boria et al., 2009). HFA children may understand the intentions of others cognitively but lack the mechanism for understanding them experientially (Cattaneo et al., 2007).

It is significant to note here, that the accuracy of mirror neuron information is defined by the accuracy of the internal motor image onto which it maps. The former can only be as good as the latter. As such, it is highly likely that mirror neuron dysfunction is secondary to individual motor planning disturbance in autism, across goal-oriented action-chaining (Cattaneo et al., 2007).

Autism and Vitality-Forms

There are four dimensions to understanding and pre-empting another person's actions. There is the practical *what* of an action (for instance, *she moves her arm, grasps a cup*). Children with autism, as compared to TD children, demonstrate no difficulties in interpreting the *what* (Boria et al., 2009). Then there are three dimensions which communicate different aspects of intention: the *how*; the *emotion*; and the *goal*.

The *how* dimension is communicated by *vitality-forms*[10], a term which refers to the affective energetic vector of a particular (potentially communicative) act: a waving hand could be vigorous (possibly welcoming, possibly warning) or gentle (possibly kind, possibly hesitant). "By recognizing the vitality-form of an action, one can appraise the affective/cognitive state of an agent as well as his/her relationship with the action recipient" (Di Cesare et al., 2014, p. 951).

Children with ASD, as compared with TD children, demonstrate significant differences in vitality-form expression (Casartelli et al., 2020a), and challenges in recognition of TD vitality-forms (imitation studies – Hobson and Lee, 1999; similarity judgments – Rochat et al., 2013; immediate evaluations – Di Cesare et al., 2017a).

Temporal Integration of Multimodal Information for Motor Planning: The Neurobiology of a Core Feature in Autism

Recent functional near-infrared spectroscopy (fNIRS) data suggest that, during tasks designed to elicit SMS, children with high-functioning autism (as compared with TD children) display hypoactivation in the *middle and inferior frontal gyri* (MIFG) as well as *middle and superior temporal gyri* (MSTG), while showing hyperactivation in the *inferior parietal cortices/lobule* (IPL) (Su et al., 2020). Here, IPL hyperactivation suggests dysfunction[11]. The IPL is an association cortex, where multimodal information becomes integrated for the tagging of motor acts (Mountcastle et al., 1975; Yokochi et al., 2003; Fogassi et al., 2005).

Goal-oriented action-chaining engages a network of cortical regions [pre-motor cortex, supplementary motor area (SMA), and pre-SMA] which loop information *via* critical subcortical bodies (including the basal ganglia and cerebellum) and route information *through the IPL* (Fogassi et al., 2005; Bonini et al., 2011; Rizzolatti et al., 2014; Rizzolatti and Sinigaglia, 2016). Vitality-form expression (Di Cesare et al., 2015, 2018), vitality-form recognition (Di Cesare et al., 2014, 2016), and vitality-form mental simulation (Di Cesare et al., 2015) involve activation of the dorso-central insula[12], a pathway which links sensorimotor cortical areas with the limbic hippocampus, including the IPL and MFIG (Di Cesare et al., 2017a).

Crucially, the IPL is *the* region of functional overlap between networks responsible for SMS, goal-oriented action-chaining, and vitality-form recognition. Concurrent dysfunction in these networks, overlapping at the IPL, gives significant weight to the hypothesis that autism involves primary dysfunction in the temporal integration of multimodal information for motor planning.

Yang and Hofmann's (2016) meta-analysis of functional magnetic resonance imaging (fMRI) studies assessing disturbance in imitation (in response to observed action),

[10] *Vitality-form* is synonymous with *vitality affect* (Køppe et al., 2008; Stern, 2010).

[11] A note on interpreting functional imaging (fMRI and fNIRS) data: Isolated interpretations of the relationship *between* activation level (hyper or hypo) in any one brain region *and* functionality of that region are extremely limited. For instance, hyperactivation of the IPL in autism could equate to: the IPL working well; the IPL working hard to compensate for internal or external dysfunction; or the IPL being disrupted by too much internal neural activity (i.e., overproduction in which functional connections are lost, Courchesne et al., 2001, 2003). To gain a clearer picture, we triangulate: TD/HFA comparison of IPL function; TD/HFA IPL-related behavioral comparisons; and any (dys)functional overlap between the various functional networks which recruit the IPL.

[12] Alterations of insula gray matter volume have been reported in individuals with ASD, as compared with TD individuals (Kosaka et al., 2010; Cauda et al., 2011; Ecker et al., 2012).

concludes that the strongest significant effects, distinguishing TD-ASD populations, were exhibited in the anterior IPL.

What Does Disrupted Bidirectional Social-Motor-Synchrony Look Like in Play?

Here, we illustrate several of our working concepts with an extended example. In a study involving micro-analysis of home video tapes of two infant monozygotic twins, early interaction differences were described between a typically developing girl (Twin TD) and her twin sister with autism[13] (Twin A, 11 months-old, pre-diagnosis), both playing a game ("*The Monster Belly Blow Game*") with their father (Trevarthen and Daniel, 2005). The video analysis was done retrospectively, after Twin A received her diagnosis at 3 years old. The recorded interaction with Twin TD involved three, almost identical iterations of the game (**Figure 2**).

Each game (described by a co-regulatory narrative arc) begins with a moment of orientation between Twin TD and her father. In most iterations this is described by the father initiating and Twin TD close-on-immediately orientating with eye-contact and increased motor tonus. The game then develops, with the father building playful anticipation through three to four iterations of a particular *extended moment* of social stimulation – "*the monster arrives*" (combining looming and vocal contours of rising volume and pitch).

We consider such extended moments to be basic units of interaction – building blocks of a developing game, 2–8 s in duration[14], which we are calling *phrases*. Phrases of play can vary greatly in their look and feel. Sometimes a phrase will have its own contour, itself constituting a small *narrative arc*, which becomes nested into the larger co-regulatory narrative arc of the game. Many early game structures include several iterations of such phrases strung together in series or combination, nested in the *development* stage of the game (**Figure 1**). Often, each iteration involves a step-up in *playful anticipation*, an energy which looks and feels very different depending on the mood of play: the quiet wonderment of a whispered suggestion; the nervous joy in the not-quite-sureness of "hide-n-seek"; the raw joyous anticipation of "peek-a-boo"; or the angry edges of challenging or rough-and-tumble play. The joy of this anticipation, even more than its culmination in a peak, impels the child's expression of, "AGAIN!". The repetitious layering and rhythm of phrases supports fluid synchrony of attention, anticipation, and action – providing each player with information, impulse, and momentum about the near-future actions of the other.

Back to the Game. Twin TD remains transfixed and displays heightening anticipation throughout. Each game then reaches its peak with a "*monster belly blow*" from the father (physical stimulation – blowing on and tickling belly – with an accompanying "growl" of high volume, low pitch, and playful gravelly timbre). A period of withdrawal and self-regulation then occurs as Twin TD breaks eye-contact and releases motor tonus. This is a proactive stage, however, as Twin TD is waiting for re-initiation from her father and responds close-on-immediately when he engages. The second game (a new narrative arc) begins.

Twin A displays asynchrony in attention, behavior, and motor tonus, and her behavior lacks any coherent build-up of arousal or anticipation (**Figure 2**). The attempt at play with Twin A lacks structured phrases or a narrative arc – it is not a game at all. Twin A's behavioral style does not promote or modulate, in her father, the typical impulse to engage with graceful rhythmicity. Already (remember the twins are only 11 months old, way in advance of diagnosis, with the parents retrospectively reporting no concerns) the father has tacitly and completely adapted his interaction style. Wanting, naturally, to make his daughter happy, the father has dropped all attempts at social build-up with Twin A reverting, instead, to frequent moments of purely physical stimulation (the *"monster belly blow").* Sadly, this natural adaptation will likely perpetuate asynchrony and asocial behavior in Twin A as she develops. The father, like many parents and practitioners, needed encouragement and therapeutic tools with which to tailor specialized attempts to connect with his daughter with autism.

Summarizing Working Assumptions (1)

Support for social timing should facilitate perceptual discrimination, timing, and contiguity of sensory input (for instance, reducing audio "noise" and latency). It should facilitate the temporal integration of multimodal information for just-ahead-in-time motor planning, and the just-ahead-in-time prediction of an other's communicative acts. It should facilitate the rhythm and phrasing of play. It should facilitate alignment of the movement/sound patterns of client and practitioner into good enough synchrony. Co-regulatory SMS should include a wide range of synchronous experience and involve a variety of narrative arcs in which partners travel together through different types and levels of arousal and back to calm.

RHYTHMIC RELATING FOR AUTISM: ESSENTIAL PARAMETERS

Good-Enough Social Timing and Learning Through Repair

Social timing and reciprocity are by no means seamless in TD infant interaction. Playful partners flow in and out of levels of synchrony. Sometimes partners share *Simultaneity*[15], (traveling alongside each other, directly in-sync), experiencing concurrent occurrences of specific behaviors in parent and child, such as the co-occurrence of social gaze, vocalizing together, the matching of arousal level, or the coordination of parent affectionate touch with infant social gaze (Feldman and Eidelman, 2004). Sometimes partners share *Complementarity*

[13]Diagnosed at 3 years old, *Infantile Autism* (ICD-10 6A02: World Health Organization, 1993); later clarified, HFA - author's confirmation, 2022.

[14]Corresponding to the extended "now", or the *psychological present moment* (Stern, 2004).

[15]Our categories here, are closely akin to Feldman's *matching synchrony* and *sequential synchrony* (Feldman, 2007a,b). Our categories have been further informed by detailed classifications within Dance/Movement Therapy (Behrends et al., 2012; Eberhard-Kaechele, 2019) and Improvisational Music Therapy (Bruscia, 1987; Wigram, 2004).

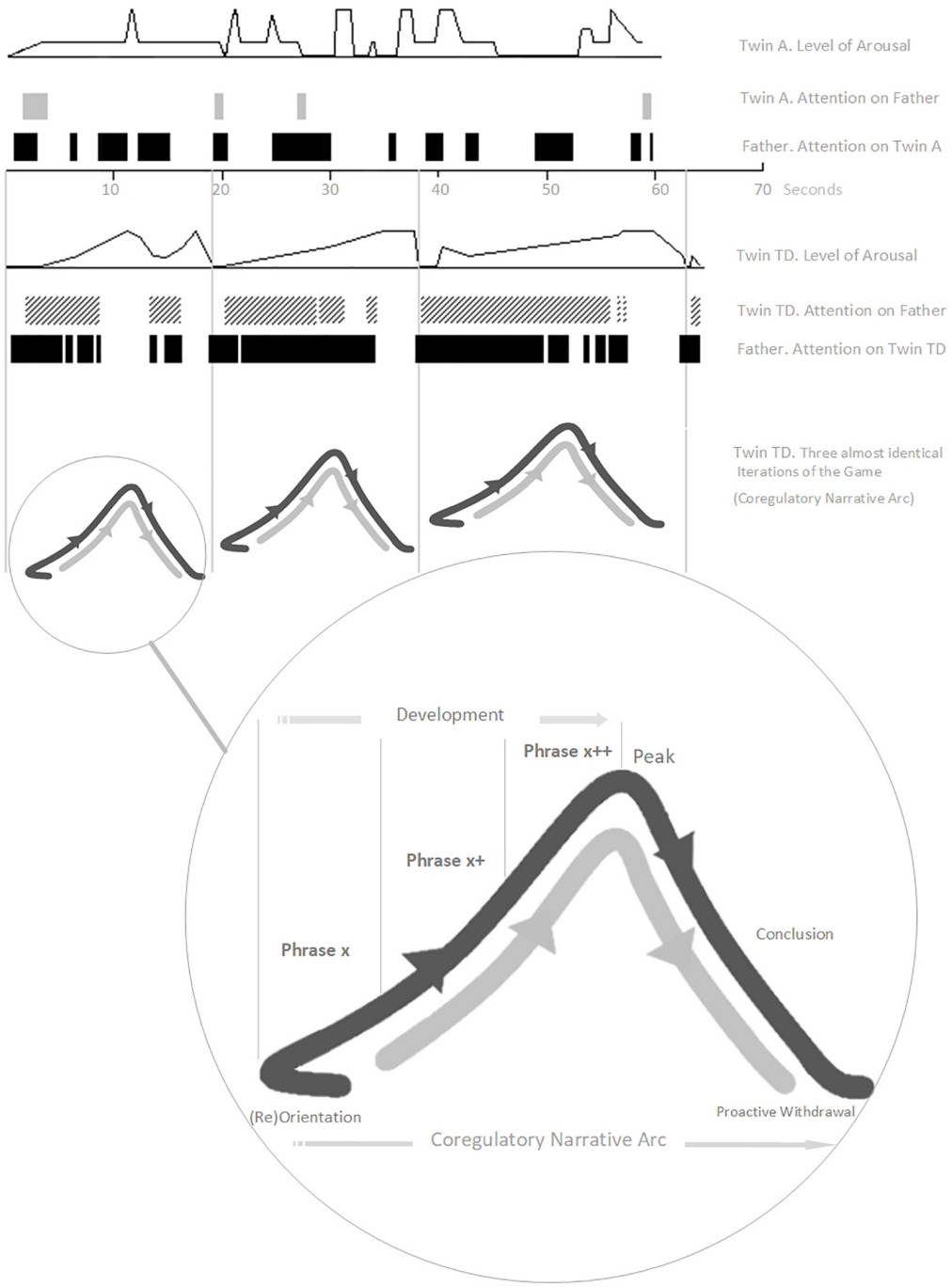

FIGURE 2 | The "Monster Belly Blow Game" (Twin TD, Typically Developing; Twin A = with Autism). The *Arousal* and *Attention* variables are aggregate scales drawn from combining relevant interactive behaviors from a tailored list developed for this micro-analysis (please see Trevarthen and Daniel, 2005, for details). Here, *Arousal* corresponds to Social Engagement System arousal. Re-presentation of findings – with authors' permission.

(the behavior of one partner complimenting the other's in timing and quality, while relating to the same pulse). In *complementarity*, behaviors often coalesce into repetitive "configurations", creating early rhythmic structures with inherent temporal expectations (Feldman, 2007b); expectations which can then be challenged and extended in playful *teasing-around-timing* (e.g., peepbo" vs. "pee. . ..p-bo!" vs. "pe-ee. . .. .p-bo!") (Wimpory, 1995, 2015). This is particularly a feature of more sophisticated (bidirectional) *mutual synchrony* whereby each partner shares a more influential role (Feldman, 2007a,b). Such playful reciprocal "double-take" of expectations, during preverbal play with, and without objects, may facilitate appreciation of the "double meanings" required

for symbolic play (Trevarthen and Logotheti, 1987; Reddy, 1991; Wimpory, 1995; Wimpory and Gwilym, 2019). Sometimes, partners are out of sync. Tronick and Cohn (1989) found that infants regularly experience interactive miscoordination, yet mismatch is typically repaired close-on-instantaneously (review: Tronick, 1989). "This constant oscillation between momentary miscoordination and interactive repair marks the essence of human dialogue, to which infants are sensitized in their earliest interactions" (Feldman, 2007b, p. 341) It is, in part, through the developing ability to recover synchrony when it goes off track, that TD infants may learn robust, flexible socio-communicative skills. For people with Autism$^{(TherapeuticNeeds)}$, of course, the initial priority is enabling good-enough synchrony and helping to repair it where needed.

Acclimatization, Simplicity and Sameness

People with Autism$^{(TherapeuticNeeds)}$ experience pervasive sensory disruption and fracturing. When this experience is acute, most often accompanied by heightened arousal levels, interaction is unfeasible. As practitioners we can help with a structured environment: minimal and consistent across all sessions; clean; low light levels; low levels of ambient sound; minimize smells; private (no disturbances); unconditional opportunities for time-out and rest. Long-term consistency of practitioner is also essential. A period of acclimatization may be a crucial precursor to potential playful interaction. In this period, practitioners should prioritize client-led sensitivity; sensitively mirroring while adding nothing; maintaining low levels of arousal; observing the client's needs, including the need for short-duration engagement, time-out and rest. As practitioners, we can be sensitive to when trust and simplicity become established – and feel carefully for those moments when our tentative input becomes feasible rather than damaging.

Engaging Existing Heterogeneous Movement and Sound

Torres et al. (2013) helped children with autism gain improved fine motor control of their hand movements. They used a co-adaptive child-computer interface (visuo-spatial and auditory) to augment each child's spontaneous movement experience and substitute corrupted kinesthetic information. The aim was to give existing heterogenous movement patterns a chance, seeing these patterns as meaningful adaptations with personal momentum and rhythmicity. The study (and the trust) worked. "... This new concept demonstrates that individuals with autism do have spontaneous sensory-motor adaptive capabilities. When led to their self-discovery, these patterns of spontaneous behavioral variability (SBV) morph into more predictive and reliable intentional actions. These can unlock and enhance exploratory behavior and autonomy in the individual with autism."

Engaging Initial Loops of Behavior

Infants with Autism$^{(TherapeuticNeeds)}$ often appear to channel the potential momentum of social engagement into interactions with the non-human environment (Trevarthen et al., 1996; Maestro et al., 2005). Disconnected from interaction, the infant's rhythmicity often appears in loops of repetitive behavior: movements and/or sounds [often referred to colloquially as "stimming" (Bakan, 2014)]; relational patterns; or configurations of object-play. The loop is a self-completing pattern, with impulse and energy within either the beat pattern of repetitive movement or sound, or the discrete behavioral steps in a section of object-play. Each beat/step is essential to the pulse of the loop, to its momentum and sense of completeness. If present, we, as practitioner, can piggy-back on that pulse. If looping regularity is not apparent, we can find ways of integrating a pulse and moving from there.

Recruiting Auditory Beat as a Tool to Facilitate Social-Motor-Synchrony? A Neurobiological Perspective

In musical experience[16], the presence of a beat enables the perception of rhythm and compels movement (Grahn and Brett, 2007; Grahn, 2012; Levitin et al., 2018). Why is this?

Pre-motor organization engages a network of cortical regions [pre-motor cortex, supplementary motor area (SMA), and pre-SMA], which loop information *via* critical subcortical bodies (including the basal ganglia, brainstem and cerebellum), and route information through the IPL (Fogassi et al., 2005; Bonini et al., 2011; Rizzolatti et al., 2014; Rizzolatti and Sinigaglia, 2016).

The SMA, basal ganglia, and the cerebellum comprise an, "extended cortico-subcortico-cortical functional network providing specific timing and entrainment sensitivities" (Nozaradan et al., 2017, p. 156), in the processing of auditory rhythm – the beat perception/generation network. Biological oscillators in these respective regions provide overlapping yet different time-signature ranges, and therefore differing functions, which complement each other in the full creation of rhythmic experience (Ivry and Hazeltine, 1995; Ivry, 1996; Grahn and Brett, 2007; Grahn, 2009; Nozaradan et al., 2017).

This beat perception/generation network shares significant structural and functional overlap with the pre-motor organization network. Oscillatory function within the pre-SMA, the SMA, and the basal ganglia in particular is integral to both beat generation *and* pre-motor organization (Grahn and Brett, 2007). The basal ganglia and the pre-SMA/SMA are richly connected through striato–thalamo–cortical loops (Alexander et al., 1992; Inase and Tanji, 1994) and are involved in the prospective timing of future movements (Alexander et al., 1992; Rao et al., 1997; Sardo et al., 2000; Tan et al., 2009). "A role for the basal ganglia and SMAs in beat induction is consistent with their involvement in motor prediction (the spontaneous response to hearing a beat is often to move at the time when the next beat is predicted)" (Grahn and Brett, 2007, p. 902).

[16]Clarifying terms from, https://dictionary.onmusic.org:
- Rhythm: "The controlled movement of music in time. It may be defined as the division of music into regular metric portions; the regular pulsation of music."
- Beat: "The regular pulse of music which may be dictated by the rise or fall of the hand or baton of the conductor, by a metronome, or by the accents in music."
- Meter: "Measure of time; the grouping of beats into regular patterns."

Accent: "The principle of regularly recurring stresses which serve to give rhythm to music."

The potential for beat-based SMS facilitation relies, of course, on intact beat-perception. Across simple and complex meter conditions, pre-SMA, basal ganglia, and cerebellar dysfunction in autism appears to be functionally specific, leaving beat-perception largely intact (DePape et al., 2012). The anatomically and functionally specific nature of basal ganglia dysfunction in particular (Rinehart et al., 2006; Qiu et al., 2010) may likely allow for a window of beat-based support.

Schweep Schwop Not Tick Tock: Information-Rich Rhythm Helps Individuals With Autism to Predict

Knight et al. (2020) presented moments of potential *prediction error* (when a sound occurred earlier than expected in a regular series) to individuals with ASD (recruited *via* a multi-level assessment to factor out possible confounding variables; 6–21 years.). As discussed in section "Prediction, social timing, individual motor planning, and social motor synchrony in early autism," hypersensitivities, sensorimotor "noise," relative latency, and disrupted multimodal integration all have the potential to set people apart in time and disable just-ahead-in-time prediction. In section "Autism and Auditory-Temporal Processing" in particular, we outlined the case for predictive delay and/or asynchrony in autism in response to isolated sonic events. However, when presented *within simple or complex rhythms*, prediction error was completely absent – no difference was found in ERP response patterns between individuals with ASD and neurotypical controls (Knight et al., 2020).

Importantly here, our concept of rhythm is *information-rich*; full of temporal and non-temporal cues (potentially multimodal) to guide participants to on and off-beat moments in time, intention, and action. This is crucially different from the clinical tick-tock of the metronome. A meta-analysis of "tapping studies" (Yoo and Yoon, 2019), included six studies which examine unilateral (simple) movement response patterns[17] (i.e., basic tapping) as a synchronization response to "auditory stimuli". All but one of these, result in ASD subjects performing worse at synchronization than TD controls (as expected, see sections "Autism and Synchrony" and "Autism and Auditory-Temporal Processing"). One study, Tryfon et al. (2017), was exceptional – demonstrating no significant difference between ASD and TD performance, and concluding non-verbal rhythm synchronization is intact for children with ASD. On examination, all of the preceding five studies presented auditory stimuli as a "paced beat" (a straight tick-tock generated by computer or metronome). Tryfon et al. (2017) presented audio recordings of woodblock *rhythms* (complex, medium, and simple meters). We suggest this stand-out feature, in relation to the stand-out result, is not coincidence.

Yoo and Kim (2018) explored the impact of dyadic drum playing on children with HFA, concluding that the presence of rhythmic cueing and sensitive tempo adjustment correlated with improved measures of social skills. Recruiting this information-rich rhythmical interaction as an intervention over time, Yoo and Kim (2018) facilitated synchrony between children with ASD and neurotypical partners. After the intervention, participants showed decreased asynchrony when tapping with a partner at adjusted tempi, and showed greater engagement in joint attention and action.

Forti et al. (2020) developed a synchrony training program in which children with ASD were shown a progression of meaningless arm movements, with associated melodic/rhythmic scaffolding, and were asked to imitate the movements. Over 6 weeks, the children improved across increasingly difficult task variants in measures of synchrony and imitation (ibid.). Srinivasan et al. (2015) demonstrated that, over 8 weeks, children with ASD benefited from a rhythm-based movement intervention, displaying improvements in body coordination, imitation/praxis, and interactive synchrony.

In a study designed to compare music versus non-music interventions, ASD groups were assessed before and after on measures of social communication and resting-state functional connectivity of fronto-temporal brain networks (Sharda et al., 2018). Over 8 – 12 weeks the music intervention group (where improvisational approaches, involving song and rhythmic scaffolding, were used to target social communication and sensorimotor integration) scored significantly higher on a measure of pragmatic communication ($P = 0.01$). Significantly ($P < 0.00001$), post-intervention resting-state brain connectivity was *lower* between auditory and visual regions in the music compared to the non-music groups, *showing a reduction in disruptive over-connectivity* (known to be prevalent in autism, ibid.; + see Courchesne et al., 2001, 2003).

The human ASR is a neurophysiologically fast and direct response to certain sudden, unexpected auditory stimuli. ASR latency – the time from presentation of the startling stimulus until neural response – provides an index of neural processing speed. As discussed in section "Autism and Auditory-Temporal Processing," individuals with autism demonstrate prolonged unmodulated ASR latency as compared with age-matched TD controls (though without controls for LD, Ornitz et al., 1993*). Understanding the conditions which modulate latency is important for us here as, if we can minimize relative TD-autism latency difference, we can improve alignment for synchrony. When startle stimuli were presented with pre-stimulation and/or with habituation[18], latency differences and auditory hypersensitivities (shown *via* ASR amplitude) became non-significant (ibid.). Clearly, predictive information – through context and familiarity – matters.

Rhythmic Relating will build on the pulse inherent in the client's movement, sound, or object-play and augment it with clarifying qualities and tailored multimodal cues. This client-centered rhythm will provide a flow of predictive information and compelling pulse – clarifying the practitioner's communication and providing a framework to facilitate sensory contiguity, discernment, prediction and just-ahead-in-time planning.

[17] For this specific purpose we rule out Kaur et al., 2018, as their synchronization tasks were all complex multi and bilateral coordination tasks.

[18] Participants with ASD were slower to gain the benefits of habituation, needing a longer period before ASR latency effects were minimized, as compared with age-matched TD controls (Ornitz et al., 1993*).

Recruiting Acoustic Brain-Stem *Turbulence*: Evolutionary Sounds That Move Us

Recently an innovative computational approach to the automatic categorization of music (X-System) has proved successful in predicting emotional, arousal, and mood responses to music (Sice et al., 2020). Certain specific psychoacoustic qualities produce extremely direct, evolutionarily pertinent responses in humans. These include *ASR-stimuli* and *acoustic activation contours*. Sice et al. (2020) have used the term *brain stem turbulence* to describe these sounds, with reference to the degree to which these sounds constantly change in ways which activate and move us.

The ASR operates along a pathway leading directly from the cochlea, along cranial (auditory) nerve VIII by way of the lateral lemniscus, to the caudate reticular nucleus. From here, there are descending projections to spinal and limb motor neurons, provoking the "jump" or "blink" effect (Frankland et al., 1997; Osborne, 2009).

Acoustic activation contours are evolutionarily significant sounds indicative of the positioning and movement of the human body in space and time (from sudden approach, to slowly moving away). This may extend from separation cries (Panksepp, 2003), or the hissing of snakes (Erlich et al., 2013), to rapidly approaching sounds, glides, falling, fast crescendos, bursts of sound and the like. It is very likely that these sounds are recognized by innate systems early in auditory pathways (Erlich et al., 2013; re: the Inferior Colliculus, Jorris et al., 2004; Sivaramakrishnan et al., 2004). There is clear evidence of these pathways ascending to emotional systems (Heldt and Falls, 2003), as well as a descending, emotional "feedback" pathway from the amygdala (Marsh et al., 2002).

Music plays with the use of turbulence, specifically taking the "dangerous" edge of activation and, through context, timing, and expectation, leveraging that energy for joy, wonderment, and anticipation (Osborne, 2020). Moments of *relative acoustic startle* can provide defining beats and turning points. *Acoustic activation contours* can, individually, stimulate changes in mood and energy, and, used as repeating rhythmical structures, they can define the mood of extended moments or of a whole piece of music.

Turbulence compels response through movement. Turbulence is neurophysiologically direct vitality communicated instantaneously *via* sound. *Sensitive* use of turbulence may provide people with autism with a palette of sounds which represents their *most-direct* audio experience (relatively decreased latency and increased signal-to-noise ratio). This *sensitive* use will include tailored multimodal experiences, time given for familiarity and habituation, and modulated volume within an information-rich rhythm. Most clients with Autism(*TherapeuticNeeds*) will find loudness intolerable (stimuli > 80 dB – which is akin to shouting, twice as loud as conversation) (Khalfa et al., 2004), and some may be hypersensitive to particularly high-pitched sounds at normal-to-mid-range volumes (Rosenhall et al., 1999; Takahashi et al., 2014, 2016). For many clients then, we could start quietly, experimenting with *relative acoustic startle* and low-volume *acoustic activation contours*. As such, we may be able to use turbulent rhythmic structures (accents and contours) to add guiding information and energized pulse into interaction with a client with Autism(*Therapeutic Needs*).

Turbulence may also help us share emotion, mood modulation, and co-regulation. Akin to its use in music, when turbulence is presented sensitively within interactive social rhythms (defined by structure, predictability and safety – i.e., the absence of threat) the mobilization (fight/flight) potential of turbulence is likely to become the stuff of joy, anticipation, and play (Porges, 2021; Porges and Daniel, 2021).

Here, we introduce the concept of a *tonescape*: a "landscape" of interactive possibilities, spanning a wide range of modulated turbulence and synchrony; a landscape full with a variety of co-regulatory narrative arcs, leading partners in and out of varying levels of arousal and emotional tone. The tonescape can bring opportunities for small-step co-regulation and layered SI. The range of modulated turbulence in the tonescape, reaches from the poignance of peace shared, to the wonderment of subtle variation (playful, fluid, unexpected, an emotional "hide-n-seek"), to the raw joyous anticipation of "peek-a-boo."

The Versatility of Activation Contours

Activation contours are short expressions of quality which stimulate an (inter)active state change. They are single events, often multimodal, communicating vectors of intention in movement and sound, containing "...the felt experience of force... with a temporal contour and a sense of aliveness, of going somewhere" (Stern, 2010, p. 3). Activation contours can be the building blocks of a developing game – shared experiences in repetition or combination. They can be tools for the embodied reflection of vitality. They can be recruited as stand-alone events, promoting interest and motivation if things feel stuck. And they can also be integral to rhythmic synchrony scaffolding (see later) as up-beat guides to an on-beat shared moment.

Activation contours come in a huge variety and subtlety of types. Here we describe seven of them – possibly the most prevalent in interaction[19], and those which we have found most useful to consider in practice:

Up-Swish – an upwards inflection guiding toward a moment in time, space, expressed energy, and emotional tone.
Down-Swoosh – a downwards inflection guiding toward a moment in time, space, expressed energy, and emotional tone.
Stretch – a consciously elongated up-swish or down-swoosh.
Burst – an instantaneous, exploding energy often in an outward, interactive vector.
Quick-fade – the opposite of the burst, an instantaneous imploding, withdrawing vector.
Waver – a wavering vector in either an up-swish, down-swoosh, or an even plane.
Pulse – a pulsing vector in in either an up-swish, down-swoosh, or an even plane.

Activation contours can be expressed in any sensory modality or combination of modalities. When envisioning combination possibilities, we have found the following constructs useful (some single-, some multi-modality):

[19] Our categories are synthesized and developed from Stern (1993; 1999; 2010).

Volume – volume change (including silence).
Proximity – positional change (relative to the other player).
Embodiment – whole-body, postural change.
Intensity – change in the level of energy invested.
Pitch – audio pitch change.
Timbre – vocal emotional-tone change.

The "*Monster belly blow*" game (section "What Does Disrupted Bidirectional Social-Motor-Synchrony Look Like in Play?") involved the father using a rising vocal inflection (Up-swish in volume, pitch, timbre) whilst looming in toward his daughter (Up-swish in: proximity), then a falling vocal inflection (Down-swoosh in volume, pitch, timbre) whilst looming away (Down-swoosh in proximity), and the "*Belly blow*" (Burst in volume, intensity, and timbre). Other examples are, an energetic star jump (Burst in embodiment and intensity), pulling a client along a smooth floor, cradled in a blanket, with a sideways waggle [Stretch (with interspersed Waver) in proximity, embodiment, intensity] bouncing with a client on a trampoline [Pulse (vestibular) in intensity, embodiment].

Parameters for Rhythmic Synchrony Scaffolding: Lock-on Beats

Here we introduce the concept of *Rhythmic Synchrony Scaffolding*: the use of rhythm (in any modality or combination) to match, accent, cue, augment, and develop the client's pulse in movement and sound.

Within music, beats can be easy to perceive, very difficult to perceive, or overtly non-existent. For us, a *lock-on beat* (useful in scaffolding rhythmic experience) is one that maximizes the properties which promote perceptual ease. These properties can be temporal or non-temporal.

The *temporal* properties of a rhythm can induce the spontaneous *feeling* of a beat (Brochard et al., 2003; Grahn and Brett, 2007). For a lock-on beat, it is helpful to keep a regular pattern with a simple meter, i.e., one with short duration intervals, and simple integer ratios (Essens and Povel, 1985; Sakai et al., 1999; Grahn and Brett, 2007). Simple meter patterns, as opposed to complex ones, have been shown to improve synchronization dynamics (Patel et al., 2005). In western music tradition, all time signatures (or meters) are constructed in patterns of 2 and 3 s. Our simplest meters are: 2/4 [evenly accented; defined by a march; example, the Imperial March (Darth Vader theme) in Star Wars]; 3/4 (accented, strong–weak–weak, strong–weak–weak; exemplified by a waltz); 4/4 (accented, One-and-Two-and, One-and-Two-and; examples: the straight "money-beat" which opens Michael Jackson's *Billie Jean*, or defines Mozart's, *"A Little Night Music"* and Pachelbel's *Canon in D major)*.

In beat perception, the basal ganglia-cerebellum partnership displays different patterns of activation on attempted perception of simple or complex meters (Grahn and Brett, 2007; Grahn, 2009; Nozaradan et al., 2017). Using a lock-on beat will engage the basal-ganglia/pre-motor-area relationship, as: "...functional connectivity between part of the basal ganglia *(the putamen)* and cortical motor areas *(the pre-motor and SMA)* is higher during perception of beat rhythms compared to non-beat rhythms" (Grahn, 2009, p. 35, italics added).

Lock-on beats will also simplify cerebellar processing demands and limit the demands of beat generation on the basal ganglia. In rhythm tracking studies involving patients with brain lesions, "... for cerebellar patients... *negative effects were*... specific to the rhythm played at a fast tempo, which places high demands on the temporally precise encoding of events. In contrast, basal ganglia patients showed more heterogeneous responses at beat frequency specifically for the most complex rhythm, which requires more internal generation of the beat" (Nozaradan et al., 2017, p. 156, italics added).

We can also simplify lock-on through choice of periodicity. Many potential rhythms have several levels of periodicity present. For example, in "twinkle, twinkle, little star," one can tap regularly to every syllable, every other syllable, or every fourth syllable, and still be synchronized to the music (Drake et al., 2000). Initially, we can choose to accent a well-spaced level of periodicity (for instance, the fourth syllable in the above example).

The temporal accents present in certain rhythmic patterns can act as just-ahead-in-time guides, allowing players to land on a moment of emphasis. The feel of this is "the act of raising or lifting," followed by "setting down" – like lifting a foot before making a step then placing it down with precision. The raising acts as an upbeat, anticipating and guiding the on-beat. In prosody, this is well exemplified by the iambic pentameter with an even pulse: da-Daah, da-Daah, da-Daah, da-Daah... In music, the "da-" becomes the upbeat guide to the "Daah."

In terms of *non-temporal* support, focal beats within a pattern can be accented with *intensity accents* (Grahn and Brett, 2007). These are single beats, emphasized by a change of intensity in pitch, volume, and/or timbre. Intensity accents can make impacting use of *relative acoustic startle*.

Activation contours, with their turbulent, directional energy, can help guide a player to the beat, with just-ahead-in-time advance warning. Guiding a movement toward an intended goal (moment in time; point in space; specific purpose) involves such motor prediction. TD individuals use perceptual force-time curves (with a felt sense of expected time-to-closure) to organize the effective use of force in actions, and to couple these actions with the actions of another (Lee, 1998; Rousanoglou and Boudolos, 2006; Delafield-Butt et al., 2018). In an arm-extension (for example, in expressive gesture, reach-to-grasp, or tap-to-a-beat), the motor image is a force-time curve of energetic enervation: rising on initiation, increasing to reach, falling in expectation to land on point-of-contact, or body-space goal with intention-specific appropriate force (Lee, 2009; Delafield-Butt et al., 2018). We are proposing that activation contours can serve as guides for perceptual-motor force-time curves, helping us land on beat and act in synchronous time-scales (e.g., Schögler et al., 2017).

Facilitating Quality – The Experience of Vitality

Di Cesare et al. (2017a) have shown that children with HFA have difficulties in perceiving vitality-form differences between

two contiguous stimuli (smallest change detected at >100 ms apart). This suggests that, "during action observation, children with ASD need greater stimuli variations than TD children to detect their differences in terms of vitality forms" (ibid. p8). We can support clarity in contiguity through clear isolated communicative acts. Children with autism can often recognize extreme vitality, while lacking distinction of the more nuanced vitality-forms characteristic of everyday interaction (Di Cesare et al., 2017a). Playful interaction gives us the platform to use big, distinct gestures when needed – to initiate and to clarify – and then to build toward sharing more nuanced actions.

Any one vitality-form can be recognized *via* either *visual* or *auditory* expression (Di Cesare et al., 2017b, 2018). Indeed, Di Cesare et al. (2017a) have concluded, "...it may be plausible that visual information is not sufficient for children with ASD to encode vitality forms correctly and that the use of alternative (*additional*) perceptual information may help vitality form perception" (p. 8, italics added).

Dependent on the client's level of language comprehension, we can support vitality recognition through explicit labeling of the other contextual intention-dimensions: *goal* and *emotion*. We can verbalize what we are doing and our goal; we can verbalize what the client is doing (using their name in third-person) and their goal, if apparent. We can verbalize our emotions; we can verbalize the client's gross emotional state (happy, sad, angry, excited), if apparent.

A recent study by Casartelli et al. (2020a,b) focuses on a bidirectional approach to motor dissimilarity in social contexts. Emphasized here, is the fact that TD adults demonstrate deficits in recognition of ASD vitality-forms even after information feedback (Casartelli et al., 2020b). This bidirectional finding suggests that we should avoid our neurotypical-centric interpretations of vitality-forms and, until we have spent time tuning in to our client's expressions, we should begin with simple mirroring, observation, and trust-building.

Facilitating Quality – The Psychoacoustic Attributes of Vocalizations

Using structural magnetic resonance imaging, Lai et al. (2012*) found that neuroanatomical systems that process speech and song are more effectively engaged by song than by speech, for children with ASD. We can use a melodic "story-teller's" voice (light and playful variation in pitch, timbre, volume, overall mood tone – a conscious avoidance of monotone) and/or we can literally sing our communication.

As is the case for short-interval parsing for ease of lock-on in beat perception, short spoken units support ease of rhythmic parsing in language comprehension. Whole utterances in a mother's baby-talk to very young infants tend to be short (about 0.5–0.75 s) (Malloch, 1999). They are typically repetitive and with rhythmic intonation and undulating pitch. The regular, simplified rhythms undoubtedly help the infant to synchronize (ibid.).

Sensorimotor Integration, Overwhelm, and *Layering the Senses*

As we sensitively move on from *acclimatization*, beginning to add elements to our client's rhythmic and sensory experience, we should do so only in small increments. We should add, remove, or adapt, just one layer at a time – *Layering the Senses* (Tortora, 2006). We need to be careful to observe which, and how much sensory input the client can tolerate and engage with. As functional integration occurs, we can extend sensorimotor experience in small-steps, layering in and out of the client's thresholds of sensory vocabulary and tolerance.

Summarizing Working Assumptions (2)

Piggy-backing on intact beat-perception pathways in autism, support for social timing should recruit tailored, information-rich rhythmic parameters to engage and clarify interactive pulse and relatable vitality. These lock-on parameters include beat specificity, periodicity, temporal and non-temporal accenting (including *relative acoustic startle*), and the use of *activation contours* (turbulent acoustic, and multimodal) as guides for perceptual-motor force-time curves. SMS support should facilitate good-enough synchrony as a basis for shared experience – enabling small-step co-regulation and a layered approach to sensorimotor integration. Initial and on-going environmental priorities should be acclimatization, simplicity, sameness, calm, short duration interaction, and rest. Interactive priorities should be: starting with the client's spontaneous movement, sound, or object-play[20]; isolating, accentuating, and simplifying initial focus behaviors; scaffolding with rhythm; leveraging movement (including touch) and sound in combination to maximize rhythmicity; leveraging acoustic turbulence to encourage movement-response and to simplify processing load; then extending co-regulatory experience and sensorimotor integration through small increments within a varied tonescape.

We acknowledge the pervasive nature of timing and sensorimotor disturbance in autism. We are open to the possibility of rhythm-mediated SMS *entrainment* in interaction, yet expect that (as was found by Dvir et al., 2020) such support will take the form of temporary *scaffolding*. The aim here then, is to facilitate small-step co-regulation and sensorimotor integration within a zone of proximal synchrony.

THE RHYTHMIC RELATING SKILL SET

Rhythmic Relating offers a *skill set*[21] that can be flexibly applied, as and when feels useful, when supporting playful interaction with a client with Autism$^{(TherapeuticNeeds)}$. The skill set can be used independently, or in support of the *play progression* we present in Section "The rhythmic relating play progression: building games together (from movement, sound, or object-play)." The benchmark here is the essential quality of co-creating, and passing through experiences together – synchrony for its own sake. There are no interactive expectations,

[20]Children with autism rarely display "symbolic" play (the imaginative use of one unrelated object to represent another). They do engage in two types of object-play: simple physical manipulation; and/or realistic (literal-association) play. The latter is contextually relevant play with a toy that has recognized identity: e.g., playing with a toy train as train (with sound effects, train behavior etc.). We combine both types within the term, *object-play*.

[21]The presented *skill set* is based on the preceding and subsequently cited research and the combined therapeutic and research experience of the authors.

fixed rules for progression, tick lists or programs. Rhythmic Relating is about facilitating realistically short moments of playful synchrony whilst respecting overwhelm, and the need for rest and withdrawal.

Phrases of playful interaction might be led by the client, sometimes the practitioner, often (and ideally) both in co-creation. In practice, the question of who is leading, is of far less significance than the sense of togetherness in synchrony. If the phrase is practitioner-led, then what is important is that the client is *actively experiencing* in relative synchrony. Or, if the phrase is client-led, then the practitioner should be *actively following*, ready to respond and develop. As practitioner, we can keep in mind this rule of thumb: *follow-lead-follow* (Hughes, 2004, 2011). We *follow* the client's momentum, yet we feel free to take an initiating *lead* when it feels appropriate, then *follow* again when the client picks up the flow in response or lets us know that we have missed the mark – always careful not to coerce the client.

An Overview of the Rhythmic Relating Skill Set

Please refer to the overview of the Rhythmic Relating skill set (**Figure 3**).

Embodied Mirroring Skills

In what follows, we outline a series of reflective engagement skills which range from *Selective Mirroring (Initial)* (with close affiliation to simple imitation), through to a fully embodied, multimodal reflection of the client's vitality in *Mirroring (Vitality)*. The range represents our small-step priorities: initial simplicity, low arousal, sameness, isolation and accentuation of one particular aspect of the client's movement/sound/object-play; then playful development; with extension of co-regulation and sensorimotor integration through sensitively *layering the senses*.

In deciding which skill to use and when, it is important for the practitioner to act from a place of embodied observation, attempting to immerse themselves in how the client is experiencing and communicating. Isolated, simple mirroring may be perceived as a welcome simplicity, clarity, and validation to the client with Autism$^{(TherapeuticNeeds)}$. Or it risks being perceived as judgmental and patronizing. We need to spend time attuning to find what is helpful, and always remain sensitive to adjusting, based on felt-sense feedback from the client's embodied communication.

Selective Mirroring (Initial)

We isolate a selected aspect of the client's movement or sound to mirror. We might select a behavior, gestalt, or motif for its clear, repeating nature, or because it is marked by a noticeable emotion, mood tone, or level of arousal. We want to hone in on this behavior, bring awareness to it, accentuate its affective and expressive tone (we might exaggerate or diminish our reflection for emphasis), and minimize other elements of our behavior to allow this to stand out. Here we can use big distinct movements and/or clear amplified sounds as appropriate, later, progressing toward more nuance.

Selective Mirroring (Modified)

When developing a game, we will need to be able to modify our interactive responses without losing connection with the client. While matching the overall quality of the client's behavior, we can play with modifying our mirrored movement or sound, *one aspect at a time*. Here are some aspects to consider. In movement[22]: *effort* (pace, weight, fluidity); *mood* (emotional/energetic tone); *structure* (use of body as a whole vs. in parts; place of initiation of movement; placement/movement of limbs in relation to torso; upper-lower body relationship; left to right body relationship; contralateral body relationship; place of initiation of movement); *space* (proximity – near, mid, far reach; height level changes). In sound: volume (use of accents, crescendo vs. decrescendo); pitch (contours of sounds); timbre (breathy, soft, or vibrato voice or sound); form (musical motif or pattern); tempo (fast vs. slow and changes in between); articulation/length of sound (legato, staccato, tenuto) (Bruscia, 1987; Wigram, 2004; Geretsegger et al., 2015). While maintaining the overall style, we can also play with either exaggerating or diminishing a mirrored aspect of the client's behavior.

Mirroring (Vitality)

We use our *kinesthetic empathy*, all our observation skills, to feel our best-approximation of the whole-body/whole-sound vitality-form being communicated by the client in any one moment, in series, or in a repeating rhythm (Tortora, 2006; Eberhard-Kaechele, 2012, 2019; Koch et al., 2015). Vitality-forms (including stillness and inaction); psychoacoustic dynamics (including silence); and/or extended patterns of vital quality, can be "mirrored" in various ways – the energy, shape or contour of vitality being re-communicated *in essence* (Stern et al., 1985; Wigram, 2004; Stern, 2010; Daniel, 2017, 2019). When we mirror vitality, we often use *activation contours*. We can match the energy and intensity of the client's behavior without imitating or overinvesting in the particular emotional tone. This enables a safe, congruent way to connect, without fueling negative emotional patterns. Vitality can be mirrored as:

- *An alternate expression within the same modality*, for example: a client's slow, rhythmic hand clench-and-release matched by a whole-body contract-and-open; a client's anxious moan matched by mixed-pitch bubbling sounds (up-swish contour in pitch and volume, with a high level of turbulence, matching the energy contour but without replicating or fueling the anxiety); a client's violent jump matched by large body movements flowing from the core (matching the energy release without turning up the anger).
- *A cross-modal expression*[23] (matching with a different modality), for example: the arc of a client's arm movement matched by a down-swoosh contour in pitch and volume; the pulse of a client's vocalization matched by a foot tap; a client's sad vocalization matched with a sensitive whole-body folding; a

[22] *Rhythmic Relating* draws on ideas from *Laban Movement Analysis* (LMA or L/BMA) (Laban, 1976; Bartenieff and Lewis, 1980); Tortora's related *Ways of Seeing* model (Tortora, 2006); and Eberhard-Kaechele's developmental mirroring taxonomy (Eberhard-Kaechele, 2012) in considering the key qualitative, non-verbal elements of the client's movements. We have minimized and simplified related categories to fit the *Rhythmic Relating* priorities, and to support practitioners not trained in specific movement approaches.

[23] Akin to Stern's *attunement* (Stern et al., 1985; Stern, 2010).

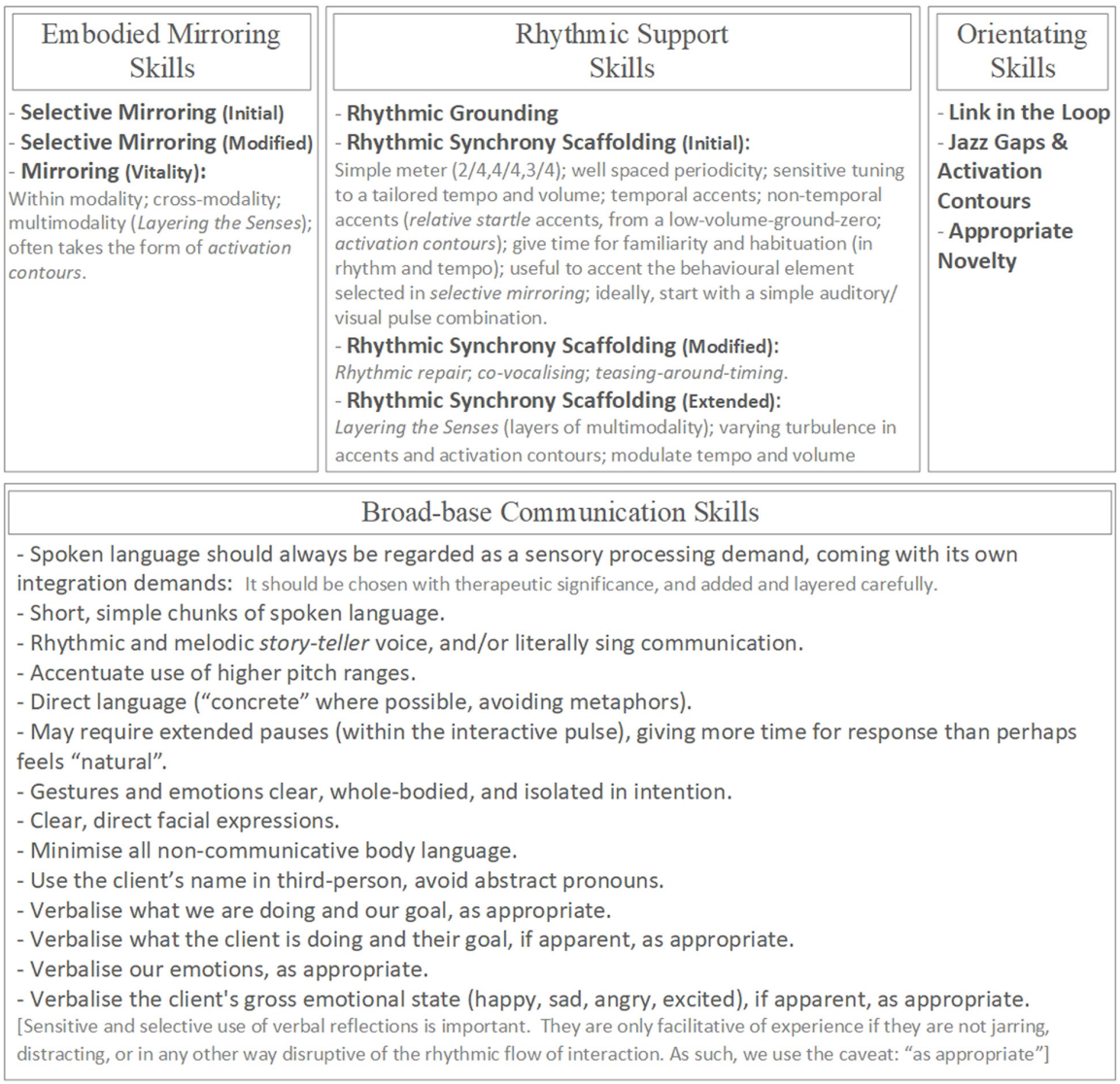

FIGURE 3 | The Rhythmic Relating skill set: overview.

client throws a pillow energetically at the wall, the arm movement matched in build-up by a playful vocalization (up-swish in pitch and volume) and then accompanied in the throw by a matching "whoooosh" (burst in pitch and volume).

- *A multimodal expression*, for example: the client is energetically pushing a toy car back and forth, practitioner adds a swaying vocalization while swaying themself; the client is pouring sand from their hand into a sand-tray, practitioner adds a vocal activation contour (stretching down-swoosh in volume and timbre – full of granular turbulence) and strokes both hands down the client's arm.

A sensitive mirroring progression (through *selective mirroring (initial)*, and on to *same modality*, *cross-modality*, then *multimodality mirroring (vitality)*, with playful *selective mirroring (modified)* along the way) is an important dimension of *layering the senses*. In conjunction with the layered use of *rhythmic support skills*, we suggest this progression represents a useful small-step approach to facilitating sensorimotor integration in playful interaction with clients with Autism(*Therapeutic Needs*).

Rhythmic Support Skills

Rhythmic Grounding

Wigram (2004) described how, in rhythmic/tonal grounding, the practitioner keeps a steady beat (simple meters – 2/4, 4/4, or 3/4 recommended) as a stable "anchor" for the client's expressions. This can be done by humming, singing, simple beatbox, repeating words, with a percussive "instrument" (drum, box, body, floor, soft shaker), or by playing a bass tone. In the early phase of interaction, this may provide a hyper-aroused client (for instance, anxious in a new situation) with a sense of rhythmical containment. Preferably, we will soon be able to pick up and match the pulse inherent in the client's current movement or

sound, and our *rhythmic grounding* will morph into the practice of *rhythmic synchrony scaffolding*. Or, if we cannot find this pulse, we continue on with the possibility that our rhythmic grounding will become integrated into the client's behavior, adding pulse and regularizing heterogenous elements. The more complex the client's behavior, the less likely we will find that initial pulse – or at least, a pulse we can readily connect with *via* a regular beat. In this case, especially with loops of object-play, we suggest rhythmic grounding can bring a useful sense of containment and momentum and be a rhythmic foundation for other Rhythmic Relating skills (e.g., *link in the loop* and *jazz gaps*, see later).

Rhythmic Synchrony Scaffolding (Initial)

Rhythmic Synchrony Scaffolding (Initial) – is the use of rhythm (in any modality or combination) to match, accent, cue, augment, and develop the client's pulse in movement and sound.

In *rhythmic synchrony scaffolding* we prioritize picking up and accenting the client's spontaneous pulse in movement, sound, or behavior patterns. We bring our expression into closer rhythmical alignment with that pulse. We make our behavior more obvious, describing intention with rhythmic accents, cues, and contours; describing what is to come, just-ahead-in-time. We may also bring clarity and energy to add to the existing pulse. Ideally, yet with sensitivity to the client's sensory preferences[24], we will start with a simple modality combination[25]: *auditory* pulse (humming, singing, simple beatbox, using percussive "instruments" [drum, box, body, floor, soft shaker], or playing a melodic instrument with percussive emphasis) and *visual/movement* pulse (repetitive movement from the practitioner, defined in space and proximity). We need, always, to be aware of our impact on the client. We need to start simply (and stay simple for as long as needed), to match and be led by changes in the client's interactive arousal levels, and not to push a sense of urgency or overwhelm with our added pulse. This is very much: *follow-scaffold-follow*.

We can choose to *accent* a repeating aspect of the client's movement, sound, or object-play. We will use simple meters: 2/4, 4/4, or 3/4. We will choose a well-spaced periodicity for our accents. For instance, if a client is swaying left to right we could accent each sway (within a 3/4 meter); if a client is hand-flapping we could accent each fourth flap (within a 4/4 meter); if a client is repeating a spoken phrase we could accent the start, end, or a rhythmically significant mid-point of the phrase (within a 4/4 meter); if a client is walking around in a loop we could accent each second step (within a 2/4 meter); if a client is sliding on the floor, pushing a toy bear, we could accent each end-point of the slide (within a 4/4 meter).

In *selective mirroring* we hone in on, accentuate, and bring awareness to a particular aspect of the client's movement or sound. In *rhythmic synchrony scaffolding* we could choose to *accent* that same aspect.

We can improve our accenting with:

- Temporal guiding information – the up-beat of, for instance, the iambic pentameter (remember, da-Dum, da-Dum, da-Dum, da-Dum – with the "da-" upbeat as guide).

- Non-temporal guiding information – we can explore the use of relative acoustic startle for focal accents; tailoring our ground-zero-volume to each client's needs (often below average conversational volume i.e., <60 dB), employing the playful "shock" factor of immediate variation in pitch, volume, timbre; using drum-like bass tones; the hiss-factor of a high-hat-like-tone; the surprise of a higher-pitched machine-like pulse (e.g. a laser gun sound effect); "magical" pulses like bell and triangle tings. Here we can also bring in sound effects (animal noises, cartoon character refrains (Homer Simpson's "Doh!" as a perfect beat), machine and vehicle sounds, impressions) and focus words as accents.

We can use *activation contours* as guides to direct the client toward on-beat timing and toward our accents. Perfect for turbulent *activation contours* are any sounds with lots of inherent movement: glides; crescendos (including "whhhooop"-like sounds); variations on playful hissing ("ssss," "ssshhh," blowing sounds); sounds with high levels of randomized internal movement (bubbling noises, raspberries, tongue wobbles); contoured spoken words (with movement in pitch, volume, timbre); contoured sound effects (cars *vrroooom*, animals *squark*, *woof*, *growl* – and if you can manage an elephant trumpet. . .!); and cartoon characters are literally designed for this, Scooby-doo's "Jshiiiicks! for example.

Here are two examples. Firstly, using 4/4, with high-energy acoustic startle to accent the two and four: one and "POW" and three and "POW" and. . ., tiiiIIISSSSHHHH "POW," the contour uses a turbulent up-swish pattern rising in pitch, volume, and adding timbre, all guiding toward the "POW" accent. Secondly, using 3/4 with playful, fairy-tale acoustic startle to accent the strong beat with a magical "TIIING": TIIING te te, TIIING te te, TIIING. . . SSSHhhhh, TIIING, te, te, the contour uses turbulent down-swoosh, falling in pitch and volume, toward a whispery timbre, guiding intriguingly to the "TIIING" accent.

We can experiment with sticking with the same patterning for some time, leveraging support from familiarity and habituation.

Rhythmic Synchrony Scaffolding (Modified)

Once we have established a scaffolding pattern in which our focal accent is a *selected* aspect of the client's behavior – for example, a vocalization - we could adjust the rhythm to bring our reflection of their vocalization into closer synchrony with our shared forward-moving pulse (and therefore, *complementarity*). This can function as *rhythmic repair* of rhythmic irregularity (Nielsen and Holck, 2020). This can also evolve into *co-vocalizing*, where we mirror elements of the client's vocalization, bring it into a rhythm, and make up "songs" (verbal or non-verbal) as a development. We have found the practice of co-vocalizing to be a useful step toward turn-taking.

Our use of a *link in the loop* (see below) relies on establishing a shared rhythmic pulse (creating expectation and momentum) and then playfully "teasing" the client's expectation. More generally, this type of *teasing-around-timing* is a crucial early developmental ingredient when building and developing

[24]Remember *pulse is amodal* and can be communicated *via* any sense. Adapt as is needed for your client.

[25]Here we describe the senses from the client's perspective.

games (e.g., peepbo" vs. "pee. . ..p-bo!" vs. "pe-ee. . .. .p-bo!") (Wimpory, 1995, 2015).

Rhythmic Synchrony Scaffolding (Extended)

As the richness of client-practitioner interaction develops, we may want to add layers of multimodality to our scaffolding (*layering the senses*). In addition to *auditory* and *visual/movement* pulse, this could include *physical* pulse (varying type, pressure and position of contact and touch), or facilitating *proprioceptive* and/or *vestibular* pulses for the client (through assisted movement – possibly using supportive equipment such as blankets, trampolines etc.). In our use of *relative startle accents* and *activation contours* we can add additional layers of multimodality and vary the range and tone of turbulence. We can play with modulating the tempo and volume of our scaffolding.

Orientating Skills

Link in the Loop

To promote an orientation, or if things feel stuck, one option is to add an element to the loop. The aim is to do something with relevance to the client's movement, sound, or object-play, yet appropriately novel (the *right level of different* – noticeable, perhaps humorous, but similar enough not to jar). We repeat this simple action or sound with regularity, at the same point in a loop. If pitched and timed well, our action or sound can become part of the loop – an integrated link. We have become essential to the completion of the loop. Here are some examples:

- *With movement*, client is running a circuit of the room, touching various points on the wall in a loop, practitioner adds *rhythmic grounding* and positions themself with their hand directly over one of these touch-points.
- *With sound*, client is humming and swaying, practitioner adds *rhythmic synchrony scaffolding* and adds their own movement (an activation contour, quick-fade in embodiment, a whole-body withdrawing and shrinking small) every fourth bar of a 4/4 meter.
- *With object-play*, client is sliding across the floor on their bottom, pushing a toy bear with their feet, practitioner adds *rhythmic synchrony scaffolding* and then creates a human-bridge (arched on all fours) for the client to pass through in their current trajectory.
- *With movement*, client is rocking, practitioner adds *rhythmic synchrony scaffolding* and rocks in synchrony, then taps the client's right hand on every fourth rock.
- *With object-play*, client is pushing a toy train around a track, practitioner adds *rhythmic grounding* and, each time the train passes the station, starts to chase the train with a toy car.

The link can replace an accent or phrase within *rhythmic grounding* or within *rhythmic synchrony scaffolding* (with or without a preceding *activation contour*). Alternatively, without rhythmic support, we can use a stand-alone *activation contour* in the lead up to a link. Then, from there, we can facilitate an orientation from the client, by either withholding the link (a *jazz gap* – see below); or changing our action or sound (*appropriate novelty*).

Jazz Gaps and Activation Contours

A *jazz gap* refers to a pregnant pause deliberately interjected into the rhythmic flow of communication. A jazz gap holds a silence longer than the natural on-beat demands. It has the energy of needing to be filled. A beat is expected, movement is compelled. We can play with the held duration of a jazz gap over a range up to around 6 s. If we push the duration much past this range, we lose the rhythmical impetus of the "here and now." "The current consensus in music psychology and cognitive neuroscience is that the ability to associate beats, or perform them meaningfully as a pulse, stops at around 6 s or 0.16 Hz. . . It is at this point that the mind and body can no longer "lock on" – either actively through playing, or passively through listening – to the rhythm as a pulse" (Osborne, 2017, pp. 18–19). We have not found studies which could provide equivalence for individuals with autism. As such, we will proceed with the tentative working assumption that the 6 s window is appropriate for the high-end of a sense of associated rhythm. Practically, it will be essential for the *practitioner* to retain their sense of the continued rhythm, and so the 6-s high-estimate remains entirely relevant to the therapeutic tool.

We can use a jazz gap within *rhythmic grounding* or *synchrony scaffolding*. We simply replace an accent or short phrase. For example, in a straight 4/4 where the two and four are accented "TISH" sounds (employing *relative acoustic startle*): One and TISH and Three and TISH and One and [Jazz Gap. . .]. Or with the temporal accent of an iambic pentameter – da-Dum, da-Dum, da-Dum, da- [Jazz Gap. . .]. Or we can introduce a jazz gap within, or at the climax of an *activation contour*. For example, in a 3/4 swaying waltz: Dum, tuh, tuh, Click, tuh, tuh, Dum, tuh, tuh, Click, tuh, tuh, whooooaaahh. . .Click, tuh, tuh, Dum, tuh, tuh, Click, tuh, tuh, whooaaaah. . . [Jazz Gap]. We can also use a jazz gap to replace an established link in the loop (see above).

THE RHYTHMIC RELATING PLAY PROGRESSION: BUILDING GAMES TOGETHER (FROM MOVEMENT, SOUND, OR OBJECT-PLAY)

Rhythmic Relating is about free-flow playful interaction. The *play progression* we describe, is a template which can be used flexibly. The *progression* may be useful in extending spontaneity toward experiences which facilitate co-regulation and SI. It may also provide a helping hand when things feel stuck.

An Overview of the Rhythmic Relating Play Progression (in Pictures)

Please refer to the overview of the Rhythmic Relating Play Progression (in pictures) (**Figure 4**).

An Overview of the Rhythmic Relating Play Progression (in Words)

Please refer to the overview of the Rhythmic Relating Play Progression (in words) (**Figure 5**).

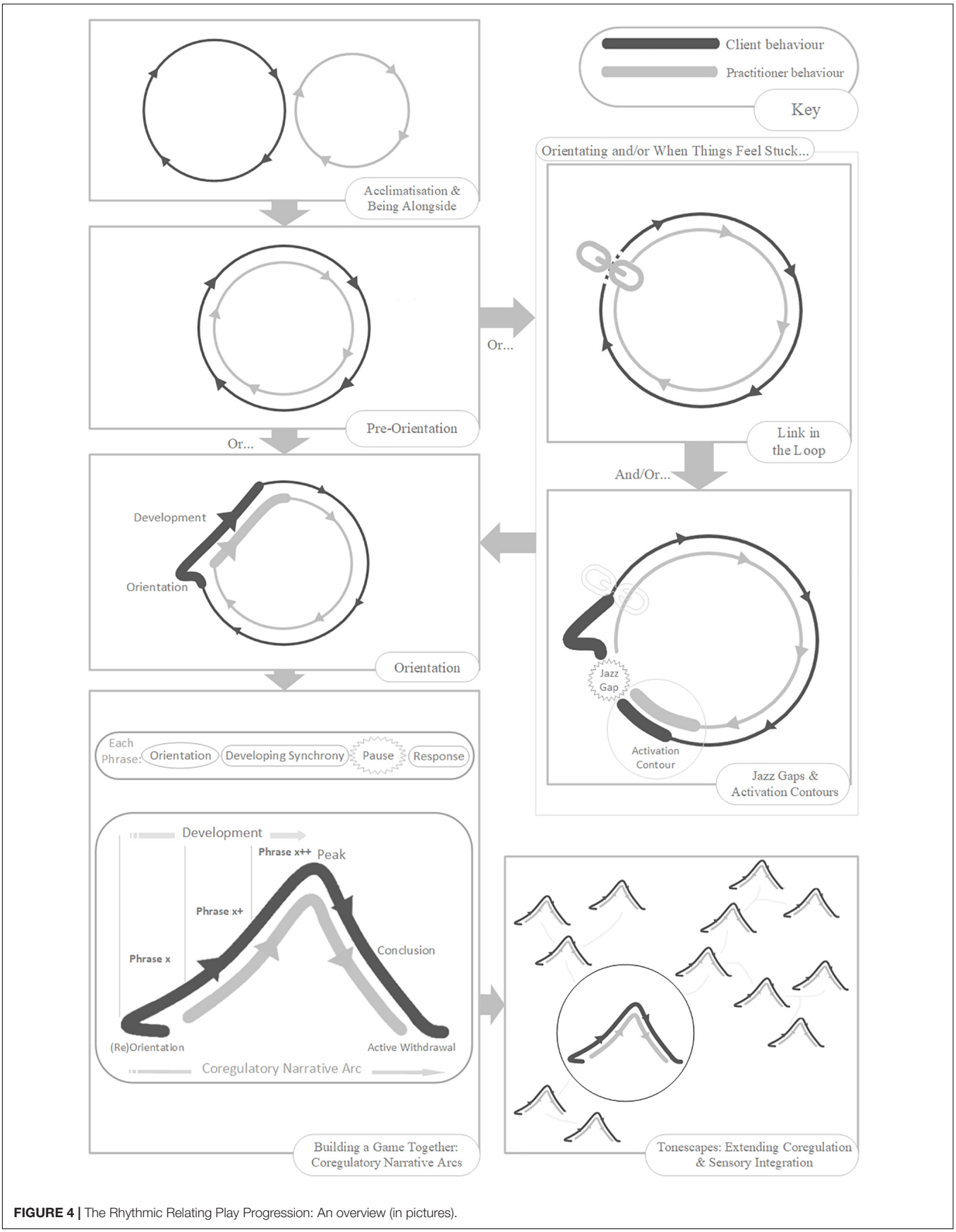

FIGURE 4 | The Rhythmic Relating Play Progression: An overview (in pictures).

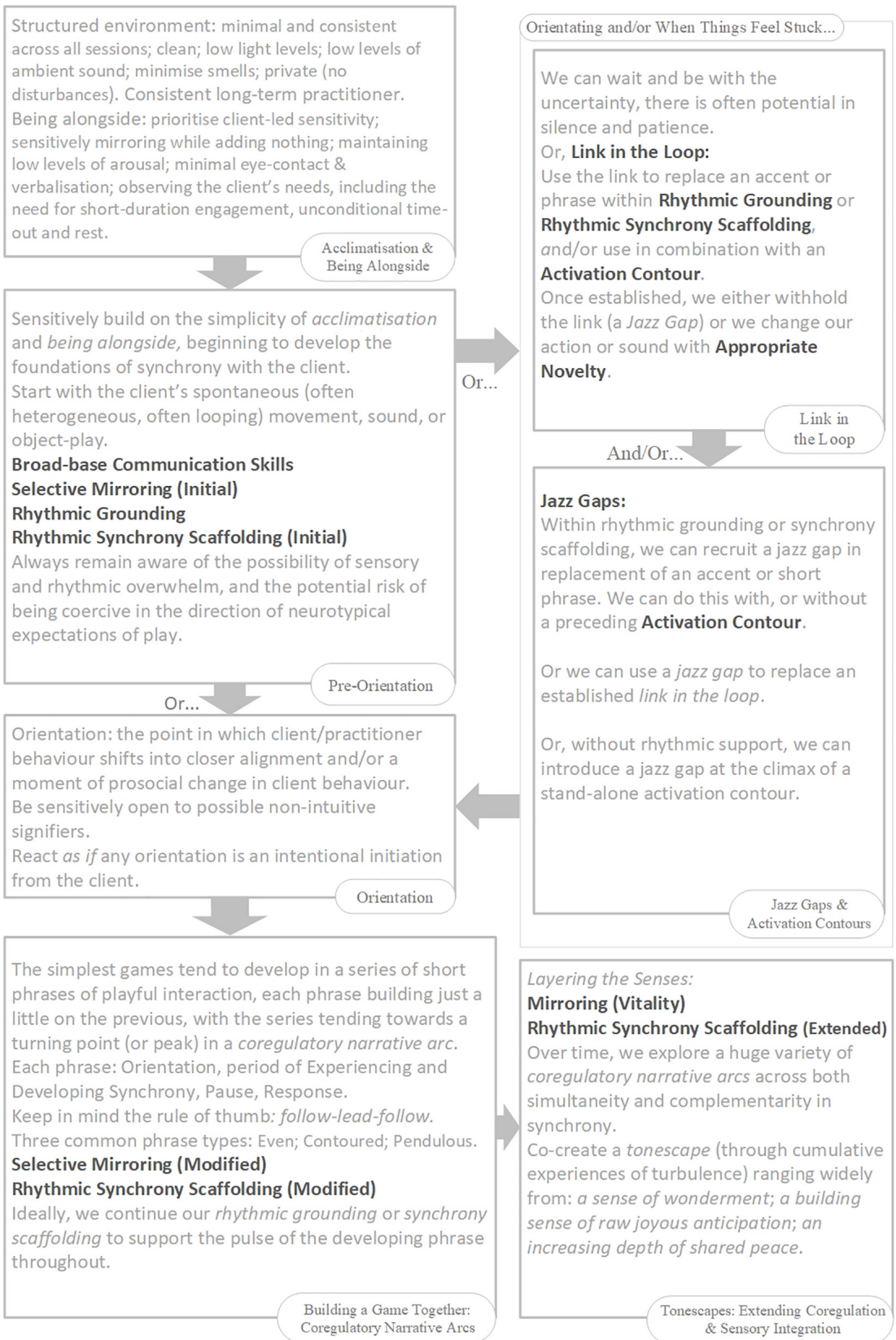

FIGURE 5 | The Rhythmic Relating Play Progression: An overview (in words).

Notes on the Rhythmic Relating Play Progression

Broad-Base Communication Skills

Applicable throughout – see **Figure 3**.

Acclimatization and Being Alongside

See section "Acclimatization, Simplicity and Sameness".

Pre-orientation

We ask ourselves, "what might it feel like to be experiencing this moment through the client's particular structuring of their movement, sound, stillness, and silence?" We aim to become sensitive to the pulse and quality of the client's behaviors. We try to tune into energy, effort, momentum, emotional color, potentially non-intuitive time-frames for response, and direction of focus. We are attempting to attune to possibilities of shared meaning that we might not initially recognize or understand.

We start with the client's spontaneous movement, sound, or object-play. We attempt to connect with a particular aspect of their behavior – s*elective mirroring (initial)* (section "Embodied Mirroring Skills" and **Figure 3**). If we are able to pick up on a repetitive, somewhat looping quality within the client's movement, sound, or object-play – use *rhythmic synchrony scaffolding (initial)* (section "Rhythmic Support Skills" and **Figure 3**). If not, we can use *rhythmic grounding* to add pulse (section "Rhythmic Support Skills" and **Figure 3**). In our rhythmic support, we should be led by the client's pulse and momentum where possible. If we are adding our own interpretation of pulse, we should be responsive to the possibility of rhythmic overwhelm (getting the momentum and mood wrong).

Orientating

If things feel stuck, we can wait and be with that uncertainty. There is often potential in space and patience. Or, as a possibility – use *link in the loop* (section "Orientating Skills" and **Figure 5**) and/or *jazz gaps and activation contours* (section "Orientating Skills" and **Figure 5**).

Orientation

In the Rhythmic Relating play progression, we have deliberately not defined a particular moment of initiation or specified an initiator. Instead, we are interested in the practitioner using the skill set, remaining sensitively open, and facilitating potential for bidirectional SMS. We consider the overt beginnings of an interactive phrase to be either, the point in which client/practitioner behavior shifts into closer alignment, or a moment of prosocial change in client behavior. Part of our practice is a continual tuning-in to possibly non-intuitive orientations from the client (**Figure 6**).

We also recommend the highly powerful practice of reacting *as if* any orientation is an intentional initiation from the client. This practice is a safety-net, ensuring we don't miss opportunities, and also promotes positive feedback loops for learned interactive behavior.

Building a Game Together: Developing Co-regulatory Narrative Arcs

The simplest games tend to develop in a series of short phrases of playful interaction, each phrase building just a little on the previous, with the series tending toward a turning point (or *peak*) in a *co-regulatory narrative arc* (**Figures 1**, **4**).

Each phrase (**Figure 7**) starts with an orientation. Broadly, there are three possibilities at this point. The orientation itself could be a shift toward synchronous alignment, with the client's behavioral pulse somewhat locking into the attempts of rhythmic facilitation made by the practitioner. Then there are two possibilities that come from the use of *activation contours* and *jazz gaps* (within our rhythmic supports): the client may have been compelled to move, to do something new; or, if we have

- Created sound.
- Mirroring an aspect of the practitioner's movement/sound/silence.
- An alignment of behavioural pulse (synchrony: either in simultaneity or complementarity).
- A pause, in expectation of response.
- Proximity (including body contact).
- Eye contact.
- Vocalization (including words).
- Specific change in play-content.

FIGURE 6 | A non-exhaustive list of possible ways a client with Autism$^{(TherapeuticNeeds)}$ might initiate an orientation.

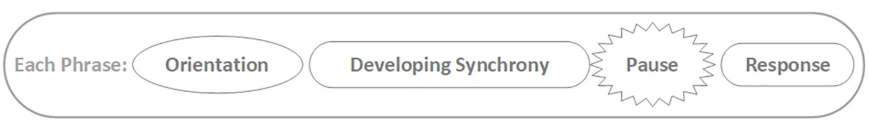

FIGURE 7 | A *Phrase* of playful interaction.

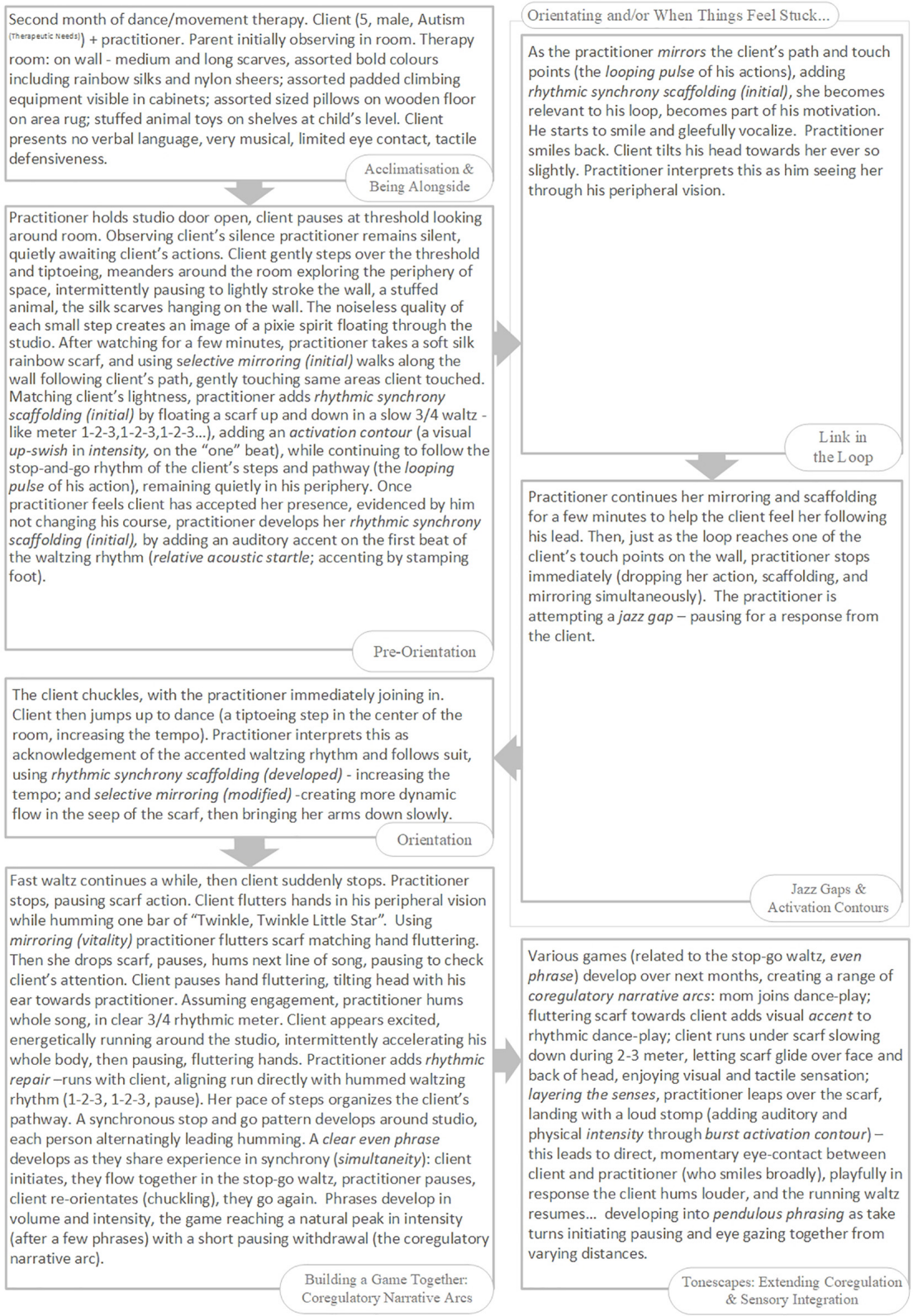

FIGURE 8 | Case example. Rhythmic relating within dance movement therapy: Suzi Tortora.

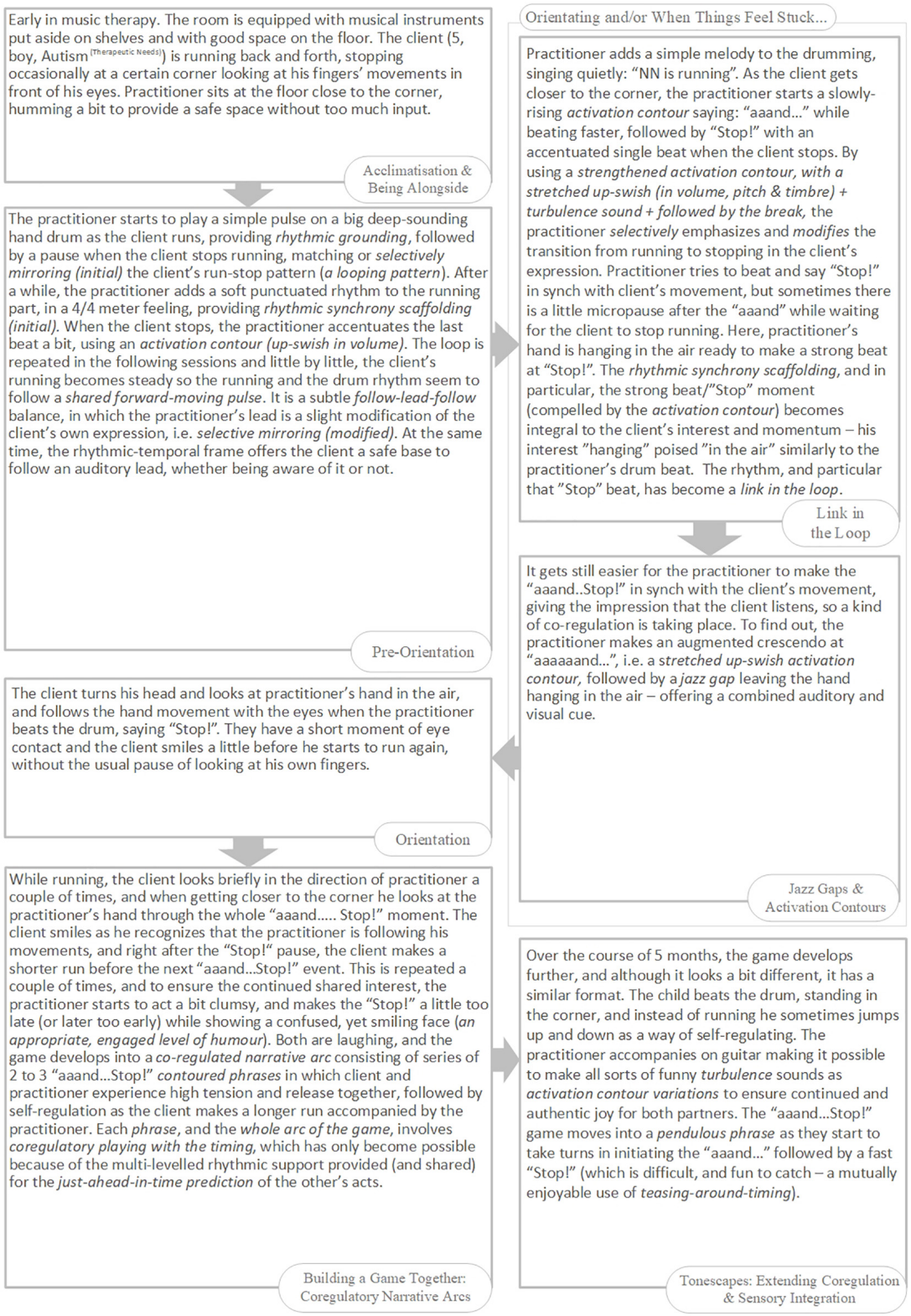

FIGURE 9 | Case example. Rhythmic relating within improvisational music therapy: Ulla Holck and Monika Geretsegger.

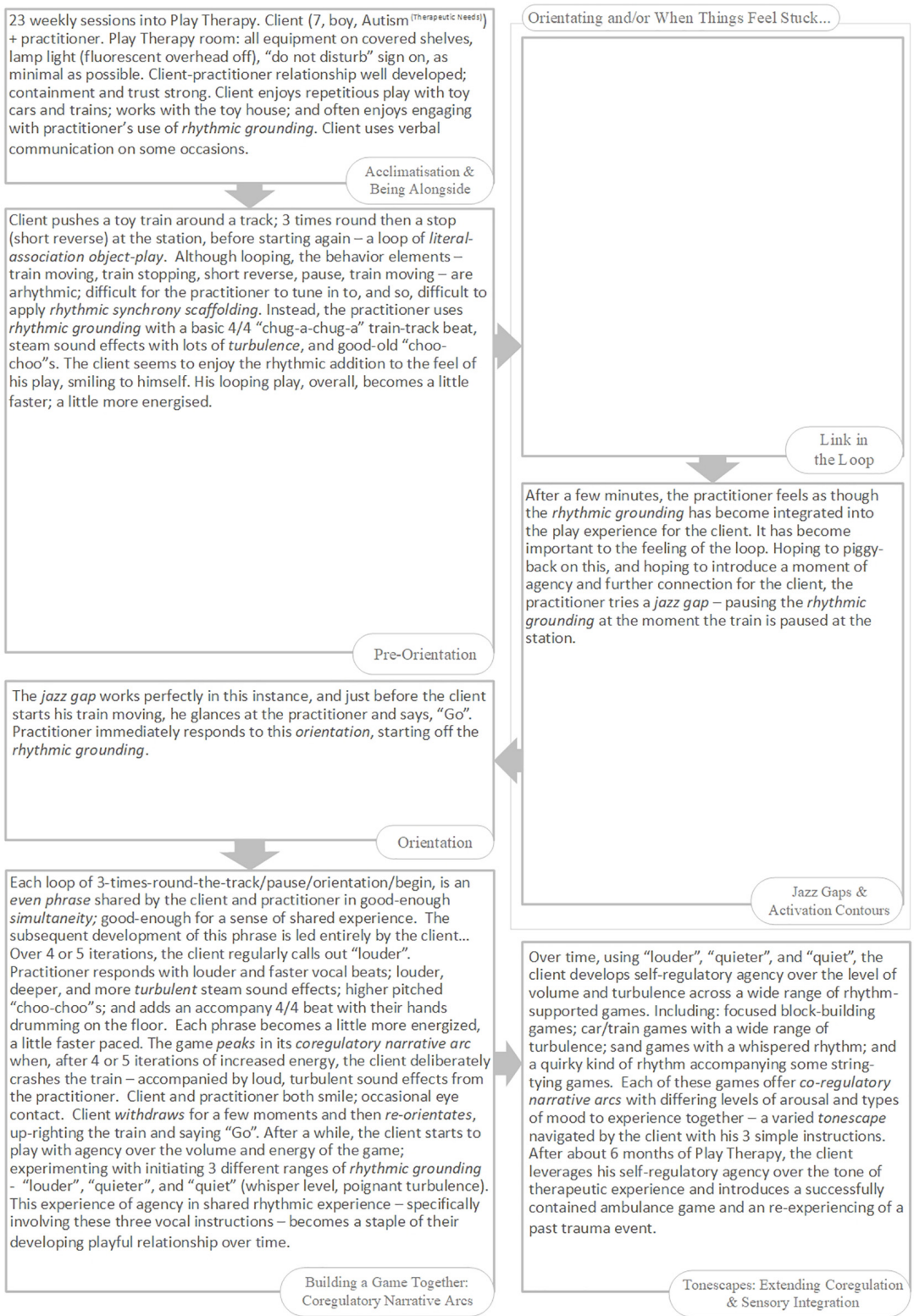

FIGURE 10 | Case example. Rhythmic relating within play therapy: Stuart Daniel.

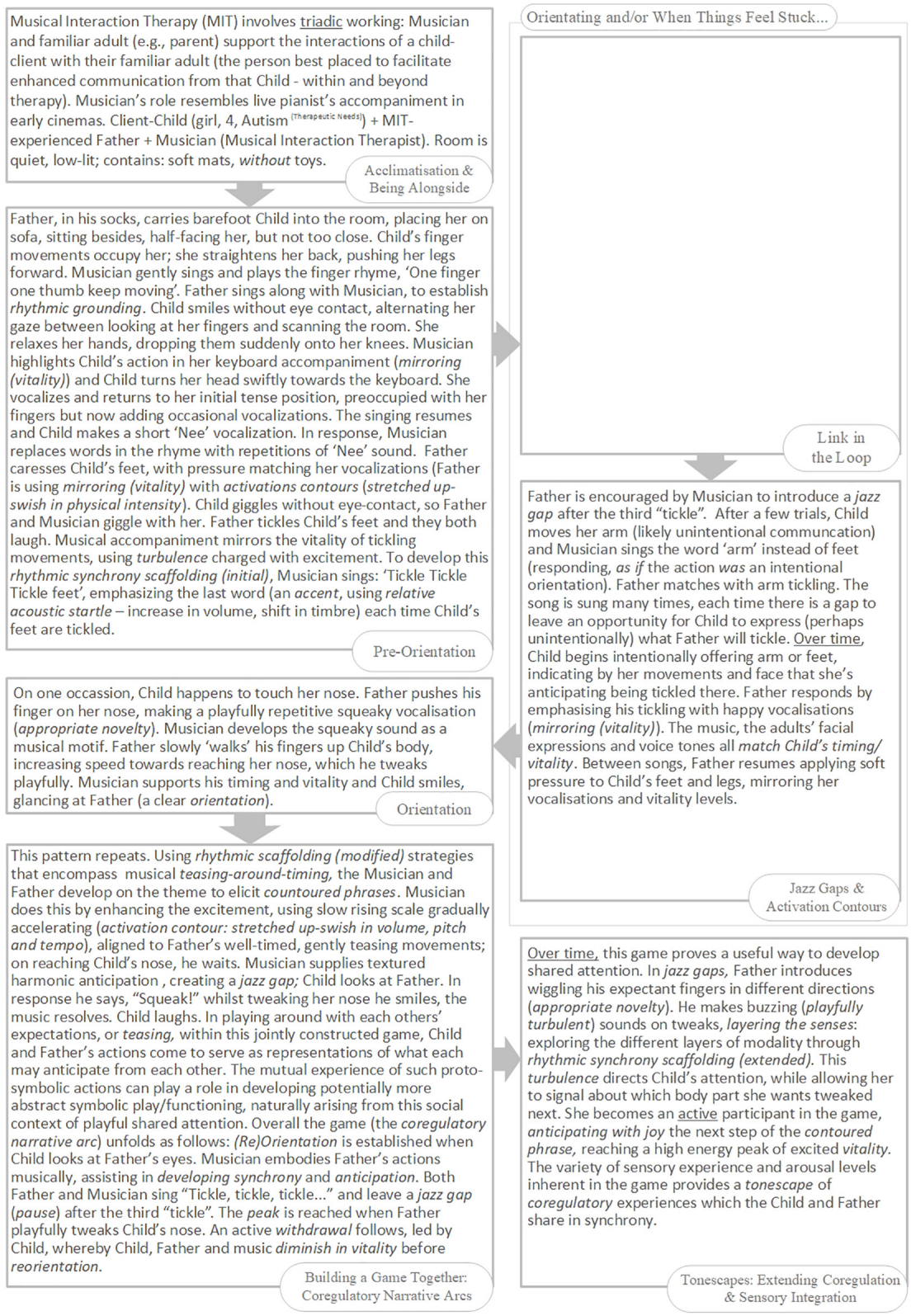

FIGURE 11 | Case example. Rhythmic relating within musical interaction therapy: Judit Elias-Masiques, Marie-Claire Howorth, and Dawn Wimpory.

introduced a *link in the loop*, the client may pause as something specific is expected of us.

As we are led into a shared period of developing synchrony, the type of orientation helps us respond and somewhat defines the terrain (the rough shape of the phrase to come: *even*, *contoured*, or *pendulous*):

- An *even phrase* is marked by both partners traveling alongside each other, through an even pulse, in simultaneity (exactly in-sync): walking; jumping; rocking; blinking; sharing a regular sonic pulse; placing Lego bricks with regularity etc. After orientation and an extended moment of experiencing our even synchrony, we can pause and seek response (preferably), or respond ourselves through *selective mirroring (modified)* (section "Embodied Mirroring Skills" and **Figure 3**) and or *rhythmic synchrony scaffolding (modified)* (section "Rhythmic Support Skills" and **Figure 3**). Then, a further orientation, and the next iteration of the phrase.

- A *contoured phrase* is one defined by an *activation contour*. Again, this experience is defined by simultaneity and traveling through the contour together. Either partner may be responsible for generating the activation contour, the other might be engaged in a relatively receptive fashion. What is important is that there *is* engagement and a sense of shared experience. After an extended moment of experiencing our contour together, we can pause for response. Contoured phrases tend to develop through increments of intensity and anticipation, tend to be repetitious in nature, building toward an overall crescendo peak (see section "What Does Disrupted Bidirectional Social-Motor-Synchrony Look Like in Play?"). The response, therefore, tends to be a subtle variation of "AGAIN"! However, there is also impact in occasionally breaking the expected rhythmic build-up through *selective mirroring (modified)* and/or *rhythmic synchrony scaffolding (modified)*.

- A *pendulous phrase* is one specifically defined by action, then response, in complementary synchrony within a shared time-frame – the simplest being the back and forth of turn-taking, the more complex being patterns of response delayed or staggered in time. We use a variation of imitation in movement or sound – *selective mirroring (initial)* - or a repetitious action in object-play (throwing a ball; sliding a soft toy; pressing a switch etc.) to develop a turn-taking dynamic. After an extended moment in this shared synchrony, we pause for response and the next phrase. We can develop the game with *selective mirroring (modified)* and/or *rhythmic synchrony scaffolding (modified)*.

Tonescapes: Extending Co-regulation and Sensory Integration

We can facilitate sensorimotor integration, depth of relatable vitality, and a range of emotional and arousal experiences, all through our sensitive practice of *layering the senses – mirroring (vitality)* (section "Embodied Mirroring Skills" and **Figure 3**) and *rhythmic synchrony scaffolding (extended)* (section "Rhythmic Support Skills" and **Figure 3**). Over time, we explore a huge variety of *co-regulatory narrative arcs* (**Figures 1**, **4**) across both simultaneity and complementarity in synchrony. Client and practitioner travel together in and out of the client's thresholds of emotional vocabulary, arousal, and tolerance. These co-regulatory arcs are like hills and mountains in the *tonescape* we travel through together (section "Recruiting Acoustic Brain-Stem Turbulence: Evolutionary Sounds That Move Us" and **Figure 4**). We co-create this tonescape, through cumulative experiences of turbulence, ranging widely from:

- *A sense of wonderment* – light-footed variation in levels of turbulence in subtle playful combinations. Alternating between different types of activation contours. Moving across varying dimensions of quality. Finding a winding path to a turning point (peak) which could feel like a whispered moment of shared significance.

- *A building sense of raw joyous anticipation* – high levels of turbulence. Sticking with the same phrase with similar activation contours, building the level of arousal incrementally. Moving forwards with increasing anticipation and momentum to a high-energy peak in release and usually laughter.

- *An increasing depth of shared peace* – minimal yet playful turbulence. Just gently together. Moving toward a peak and extended conclusion in poignant silence.

The Rhythmic Relating Play Progression: Examples in Practice

Please see the Examples in Practice (**Figures 8**–**11**) and **Supplementary Material** (Examples of Rhythmic Relating in Practice).

CONCLUSION

We have reviewed evidence of disruptions to social timing, sensorimotor timing and integration in autism. We have discussed how such disruptions affect shared timing in play and intersubjective meaning-making, so important for learning, development, and health.

We have proposed *Rhythmic Relating*: a system which aims to augment bidirectional communication and facilitate good-enough social timing; opening up the possibility of playful therapeutic interaction, small-step co-regulation, and layered sensorimotor integration. We have designed **Figures 3**, **4**, **5** (above) to be used together to provide a take-home working summary of the main features of the model. Through integrating *Rhythmic Relating* principles into a broadly child-centered therapeutic approach to interaction with clients with Autism$^{(TherapeuticNeeds)}$, we hypothesize that tailored rhythm-supported experiences of social timing will enable shared-meaning making, ease, and joy. Importantly, over time, we predict increased co- and self-regulation, reduced anxiety and challenging behavior, and greater trust in social relations.

We suggest a suite of pilot intervention studies is now needed to assess the possibility of combining *Rhythmic Relating* with different therapeutic approaches in playful work with individuals with Autism$^{(TherapeuticNeeds)}$. Such studies would assess therapeutic efficacy and allow for a fine-tuning of the model in real-world experience.

In addition, we propose two specific empirical hypotheses designed to clarify the significance of certain key features of the *Rhythmic Relating* approach:

(1) *Is rhythm a modulating factor of neural processing speed in autism?* Testing the impact of contextual ASR presentation (defined by rhythm; rhythm with activation contours as cues; and

activation contours alone), on ASR magnitude and latency, in comparison to isolated startle stimuli (all variables presented at various volumes) – for subjects: HFA, TD controls.

(2) *Can acoustic Tau-G guide synchrony in autism?* Testing the impact of acoustic activation contours as Tau-G guides across various movement acts; each which define and test different potential synchronization dynamics - for subjects: HFA; TD controls.

Further, we propose that more research is required to better understand the underpinning neurobiology and neuromotor psychology disrupted in autism, *vis-à-vis* basic human intersubjectivity predicated on shared timing, feeling, and intention.

Rhythmic Relating aims to open up the therapeutic possibilities of play. We recognize such therapeutic experience as reflecting the intersubjective characteristics of typical preverbal interactions, with a conscious emphasis on shared, affective, and embodied experiences that may otherwise remain inaccessible for people with Autism(*TherapeuticNeeds*). The emotional and developmental significance of such opportunities should not be underestimated. The dance of interactive synchrony is, "the basis of social connection and empathy; it makes people trust and like each other" (Feldman Barrett, 2017, p. 287).

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

SD contributed as lead author, developed the initial premise and working concepts for the model and manuscript, at each stage worked with the co-authors to develop the model and manuscript, and contributed to the final edit and clinical examples of the model in practice. DW contributed as primary author and editor, developed the model, and contributed clinical examples of the model in practice. JD-B contributed as primary author and editor. SM contributed as editor and developed the model. UH, MG, ST, SK, JE-M, M-CH, and KS developed the model and contributed clinical examples of the model in practice. NO, BS, PD, MR, RS, KF, and PA developed the model. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2022.793258/full#supplementary-material

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Mouth Movements as Possible Cues of Social Interest at Birth: New Evidences for Early Communicative Behaviors

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Previous studies evidenced that different interactive contexts modulate the visual attention of newborns. In the present study, we investigated newborns' motor feedback as an additional cue to neonates' expression of interest. Using videos of interactive faces and a familiarization-test procedure, three different groups of newborns were assigned to three different conditions (i.e., one condition with a talking face during familiarization and silently moving faces at test, silently moving/silently moving condition, or talking/static condition). Following studies on neonatal imitation, mouth movements were analyzed as indicators of social interest. We expected the occurrence of mouth movements in the newborns to differ according to different conditions: (a) whether or not the face in front of them was talking and (b) if the person had been already seen or was new. Results revealed that a talking face elicited more motor feedback from the newborns than a silent one and that there was no difference in front of the familiar face or the novel one. Finally, frequencies of mouth movements were greater, and latencies of appearance of the first mouth movement were shorter, in front of a static vs. a dynamic face. These results are congruent with the idea of the existence of "a sense" for interaction at birth, and therefore new approaches in newborn studies are discussed.

Keywords: neonates, motor feedback, interaction, face-to-face, imitation

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INTRODUCTION

For centuries, one of the central questions of philosophers and scientists has been focused on understanding what makes humans so special? Many authors would now claim that this is due to our capacity to interact with each other using a complex system of communication using both verbal and non-verbal cues, which makes us unique. Indeed, in everyday life, humans almost constantly interact which each other, and most of these interactions occur in face-to-face contexts. In these contexts, not only the face but also the whole body becomes powerful vectors of communication (Bruce and Young, 2000). While abundant literature exists on how adults interact with each other, less is known about the development of this capacity in the early stages (Gratier and Trevarthen, 2008; Gratier et al., 2015; Dominguez et al., 2016). In the present study, we investigated the emergence of socio-communicative behaviors during the neonatal period.

From birth, and even before birth, human infants are surrounded by socio-communicative cues. Two of these cues are speech and faces. While already in the womb, the fetus hears voices in its surrounding environment (DeCasper et al., 1994), it is only from birth that the newborn can see and hear faces talking. In the past decades or so, the abilities of newborns to process speech and faces have been studied separately. It is now known that newborns' attention is tuned to speech (Vouloumanos and Werker, 2007; Vouloumanos et al., 2010) and that newborns already have some auditory preferences, such as listening to their mother's voice compared to a stranger's one (DeCasper and Fifer, 1980) or to their native language when compared to non-native ones (Mehler et al., 1988; Moon et al., 1993). Moreover, despite a weak visual system (Braddick and Atkinson, 2011), newborns can learn and recognize their live mother's face (Field et al., 1984; Bushnell et al., 1989; Pascalis et al., 1995) and unfamiliar faces presented under photographs (Pascalis and de Schonen, 1994; Turati et al., 2006, 2008; Gava et al., 2008).

While these studies shed light on remarkable feats of the newborn infant, they did not consider talking faces as a unit and therefore the possible interactions between speech and face processing at birth. To our knowledge, only a few studies investigated this possibility. In a study (Sai, 2005), authors encouraged a group of mothers to talk to their infants immediately after birth till the test session (i.e., occurring on average 7 h later), while another group was asked not to interact with them verbally. In the test session, when the mother's face and a stranger's face were presented side-by-side, the newborns looked longer and oriented more to their mother's face than to a stranger's face only if their mother had previously talked to them. The author concluded that experience with both the mother's voice and her face during the first hours after birth enhanced newborn's encoding of their mother's face. However, because fetuses hear their mother's voice and prefer it at birth (DeCasper and Spence, 1986), it is possible that in Sai's experiments (Sai, 2005) newborns who received verbal interaction, associated with socio-communicative cues such as direct eye gaze, were reinforced soon after birth, and that this reinforcement helped them to encode and memorize their mother's face.

This possibility has been called into question in more recent studies (Coulon et al., 2011; Guellaï and Streri, 2011; Guellaï et al., 2011, 2020). Using a familiarization-test procedure, and, for the first time, videos of dynamic unfamiliar faces, the authors proposed different conditions for newborn infants. Each condition was presented to one group of newborns. In a first study (Coulon et al., 2011), infants saw during the familiarization phase either the video of a woman's face talking to them or with her lips moving but no speech sounds. Then, at the test session, they saw the photographs of the same face (i.e., familiar) or a new one. Analyses of looking times at test showed that the majority of newborns elicited a visual preference for the familiar over the new face only when the face was seen talking during the familiarization phase. To further explore the interactions between speech and facial cues, additional conditions were tested in other studies (Guellaï and Streri, 2011; Guellaï et al., 2011, 2020) (**Figure 1**). Interestingly, results evidenced that newborns

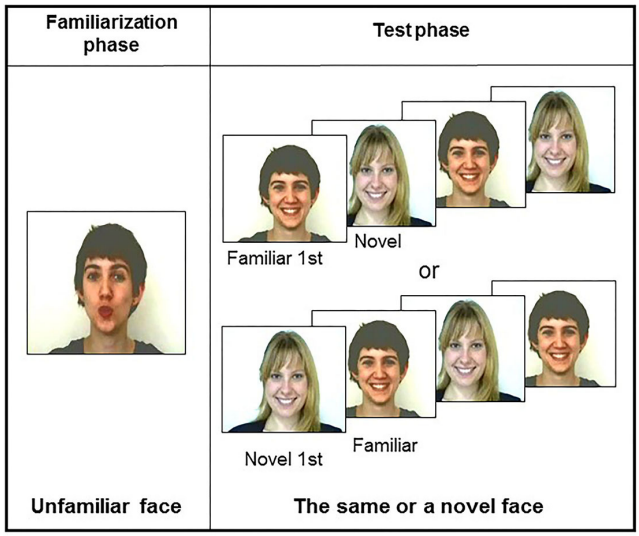

FIGURE 1 | Presentation of the procedure used for the three conditions.

recognized and preferred to look at a previously seen face only when this person talked to them with direct gaze during the familiarization phase, and when the person was seen under photographs or talking again at the test. In other words, the interactive face-to-face situation is of particular interest to studying newborns' encoding abilities of unfamiliar persons. More recently, it has been evidenced that no matter which language (i.e., native or non-native) is used by the talking face during the familiarization phase, it is the audiovisual congruent situation that is important for newborns to encode and later show a visual preference for someone who talked to them (Guellai et al., 2015).

These results evidenced that newborns already elicit a strong visual preference for persons who interacted with them verbally and that this goes beyond the mother's face. Nonetheless, one of the limits of this set of studies is that it focused on newborns' visual attention as the main cue of social interest, whereas other cues such as newborns' motor feedback could constitute additional indicators of newborns' expression of interest. In that sense, the use of videos of faces is interesting to control for different factors, such as the characteristics of the acoustic signal or the timing of the presentations. One possibility could be that the mouth movements of newborns are informative of social interest and therefore may vary depending on the interactive situations presented (i.e., talking faces, silent dynamic faces, or static faces). Indeed, some authors evidenced that the behaviors of older infants vary according to the face-to-face situation proposed (Tronick et al., 1979). Using a specific paradigm called "the still-face paradigm," these authors proposed a live face-to-face interaction between an infant and an adult, interspersed with a period in which the adult suddenly becomes unresponsive and poses a stationary neutral face while maintaining eye contact. Infants at 2 months of age react to the adults' unresponsiveness during the still-face period with

decreased visual attention and positive affect (Lamb et al., 1987). Such results are interpreted in terms of infants' affective attunement to social patterns and rudimentary expectations about the nature of face-to-face interactions (Muir and Hains, 1993). Nonetheless, to date, no study was interested in looking at newborns' facial motor feedback as serving communicative functions when presented with different face-to-face interactive situations. To identify newborns' facial gestures, we will consider those mouth movements that have been widely explored in the light of neonatal imitation (Meltzoff and Moore, 1977, 1994; Nagy et al., 2005, 2020).

Indeed, there already seem to be connections between newborns' orofacial motor capabilities and auditory and visual face information. Concerning newborns' feedback, it is well-established that newborn infants can imitate faces in the first few hours after birth, demonstrating a link between orofacial motor control and visual face perception. Other studies evidenced that newborns are able to match auditory information to motor actions. For example, they produce more mouth openings when listening to /a/ vs. /m/ sounds, and they produce more mouth closing when listening to /m/ vs. /a/ sounds (Chen et al., 2004). Moreover, facial imitation is more robust at birth in the presence of congruent (as opposed to incongruent) audiovisual speech: infants will produce more mouth openings when presented with a face saying /a/ than with the face alone, or that face dubbed with an /i/ audio track (Coulon et al., 2013).

The present study aimed at addressing two questions: (a) is there any difference in newborns' attention and orofacial motor feedback when they are facing someone talking to them or looking at them silently? (b) Would they elicit more mouth movements in front of a familiar vs. an unfamiliar person? Newborns were tested in three different conditions. Following previous studies, the first group of newborns (i.e., the talking/silently moving condition) was first familiarized with a woman talking to them in an infant-directed speech style. Then, in a test phase, they saw the familiar and a new person looking at them silently moving. The second group of newborns (i.e., the silently moving/silently moving condition) was familiarized with a woman silently moving while looking at them; at the test, they saw the same woman and a new one still silently moving while looking at them. Finally, as studies on neonatal imitation or face processing at birth used static presentations of faces during the test session, the third group of newborns was familiarized with a talking face and then presented with the photographs of the familiar and new faces at the test (i.e., the talking/static condition). We wanted to see if the face-to-face interactive situations proposed to the newborns would modulate their behaviors, in particular their mouth movements, during and after the familiarization period. Following the results of studies on neonatal imitation both in humans (Reissland, 1988; Coulon et al., 2013; Nagy et al., 2020) and non-human primates (Simpson et al., 2013), we analyzed newborns' facial behaviors as potential indicators of social interaction at birth. We expected newborns (a) to elicit more mouth movements in front of a talking vs. a silent person and (b) in front of a familiar vs. an unfamiliar person.

METHODS

Participants

The participants were 36 full-term newborns (18 girls) from the maternity hospital of Bichat in Paris. All newborns were in good health (APGAR scores above 8). The mean age was 56.4 h (range: 18–98 h). Newborns whose mothers had major complications during pregnancy and those with medical problems were systematically excluded from the study. An additional 22 newborns (10 girls; age range: 22–100 h) were excluded from the original sample because of fussiness ($n = 16$), or sleepiness ($n = 4$), or experimental errors ($n = 2$). The rejection criteria were assessed by two different experimenters.

Apparatus

Newborns were observed in a quiet room where they had been previously brought by one or both parents. Before testing, we systematically ensured that parents and medical staff gave their consent to participate in the study. Each newborn was positioned in a semi-upright position (30°) in an adapted rigid seat. The seat was placed on a table facing a 19-inch DELL color monitor, 35 cm away from the infant's eyes. Two speakers were placed on each side of the DELL monitor. A first experimenter (Experimenter 1) always stood behind the newborn during the whole session to monitor for potential signs of discomfort. A small video camera was directed at the newborn and recorded the whole experiment (the temporal resolution was 25 images/s). Images were retransmitted on two video monitors. One allowed a second experimenter (Experimenter 2) to code the duration of looking. The other allowed the parents to see their baby. The parents sat behind and far from the baby, so that the infant could not see them. Parents were instructed to not intervene (speak or come near their baby) during the whole experiment.

Stimuli

Color video films of two female faces were recorded. These videos were recorded under the same lighting conditions (mean: 16 cd/m^2) with the same white background in a soundproof room. The video framing took into account the faces of females from their top heads to their shoulders. The two women differed in terms of eye and hair color and style: short brown hair and brown eyes (brown-haired face) vs. long blond hair and green eyes (blonde face) (**Figure 1**). We chose two different faces of females so that by counterbalancing their presentation across subjects, we ensured that the results found were not due to the physical characteristics of the stimuli. Two different recordings were realized: in the first recording, each woman looked directly at the camera and addressed the newborn in the following way: *"Hello baby, how are you? Are you okay? Yes, I know, just a few hours after your birth, and we're already asking you to do things. You know, for us, it is very important to study the early behaviors of newborns like you...."* We ensured that sound intensities at the speakers in the testing room were identical for both stimuli (mean: 65 dB). In a second recording, each woman looked at the camera without talking but silently moving (i.e., translation movements of the whole head). Each of the videos created lasted for 90 s and was used in the familiarization phase.

For the test phase, either silent videos or photographs were presented (**Figure 1**). We applied the same lighting conditions to all the images (i.e., mean: 16 cd/m^2). The maximal length of each image presentation for the test phase was 60 s. Each facial image subtended about 30° of visual angle horizontally and vertically on the color monitor.

Design and Procedure

The experiment began as the infant was seated. The familiarization-test procedure was similar to the experiments conducted by Guellaï et al. The familiarization phase started with the presentation of one of the two female faces talking continuously for 90 s. Immediately after the familiarization phase, the test phase began, where the newborns saw the familiar face and a new one twice successively and in alternation. The order of presentation of the two faces in the test phase, familiar first or new first, was randomly counterbalanced across subjects by a computer program.

During the familiarization phase, Experimenter 2, unaware of the face presented, pressed and held a key button on a computer keyboard when the infant looked at the screen and released it when the infant looked away. The computer program recorded the accumulated looking times. During the test phase, Experimenter 2 proceeded in the same way, but when the newborns looked away from the screen for more than 2 s, the computer program automatically switched to the next face. A switch also occurred after newborns had looked at the face continuously for 60 s (i.e., the maximum length of each video in the test phase). The computer program also required a minimum looking time of 2 s at the screen.

Twelve newborns looked at the talking/silently moving condition, 12 others looked at the silently moving/silently moving one, and 12 additional ones looked at the talking/photograph condition. For each familiarization condition, half of the newborns saw the blonde woman and the other half the brown-haired one (**Figure 2**).

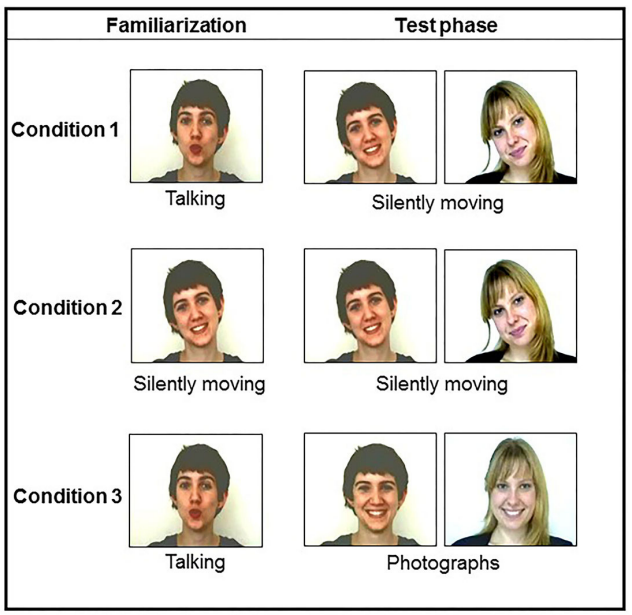

FIGURE 2 | Examples of the stimuli presented for each condition.

Data Analysis

The facial gestures of infants in the familiarization and test phases were analyzed off-line, frame-by-frame (30 frames per second) from the videos, using the Noldus Observer XT (Noldus, Wageningen, the Netherlands). Two coders, blind to the condition, scored all the occurrences of facial gestures produced by infants: mouth opening (MO), tongue protrusion (TP), lip protrusion (LP), and lip spreading (LS). Thus, a frequency corresponding to the number of mouth movements per second was defined. The mouth movements were chosen and defined according to the previous studies that investigated the neonate's behavioral feedback in imitative situations (Reissland, 1988; Coulon et al., 2013; Simpson et al., 2013). MO was operationally defined as a high-frequency opening and closing of the mouth in which the lips parted and rejoined within 2 s. TP was operationally defined as a clear forward thrust of the tongue in which the tongue protruded beyond the lips. LP was operationally defined as a clear forward thrust of the lips. LS was operationally defined as the lateral broadening of the lips and returning to their resting position within 2 s. Other behaviors, such as cough, hiccups, etc., which could involve motor actions, such as mouth opening or lip spreading, were coded but not considered in the analysis. Moreover, for each mouth movement, latencies were also considered. We expected differences in the frequencies and latencies of the overall mouth movements depending on the different conditions proposed and not necessarily on specific mouth movements. Statistical analyses were therefore performed on overall mouth movements and not on specific movements. Indeed, as presented earlier, we expected newborns to elicit more mouth movements in front of a talking vs. a silent person and in front of a familiar vs. an unfamiliar person. Finally, we also took into account infants' looking times to the stimuli, but these data are already presented elsewhere (Coulon et al., 2011; Guellaï et al., 2011). Herein, we will only present the looking times for the familiarization phase as an index of infants' visual attention. The coding comparison was made action by action (MO, TP, LP, LS, and looking times) to ensure that the two different coders scored the same event at the same time during the familiarization and the four presentations of the test phases. Observers were blind to the stimulus, and inter-observers' reliability was high throughout all the experiments (Pearson's $r \geq 0.9$). Statistical analyses were conducted using the STATISTICA 14.0 software.

RESULTS

The looking times toward the faces and overall mouth movements were taken as the dependent measure. We first checked for the normal distribution of the looking times in each condition (Kolmogorov–Smirnov test $p > 0.5$), and later also for the frequencies of mouth movements (KS test, $p > 0.3$) and for the latencies of the first mouth movements (KS test,

$p > 0.3$) for each condition during the familiarization phase. Results showed that distributions did not differ significantly from normal through KS tests. We also checked for the normal distribution of the data during the test phase for the looking times for each condition (KS test, $p > 0.6$), for the frequencies of mouth movements in each condition (KS test, $p > 0.2$), and for the latencies of the first mouth movement (KS test, $p > 0.4$). Face presentation looking times, frequencies, and latencies of mouth movements recorded during the test phase followed a normal distribution.

Familiarization Phase

Visual Attention

In the familiarization phase, the newborns looked at the video for an average of 73.7 s ($SE = 5.7$) for the talking/silently moving condition; for 72 s ($SE = 2.7$) in the silently moving/silently moving condition; and for 68 s ($SE = 4.4$) in the talking/static one. A three-way (condition: talking/silently moving, silently moving/silent, or talking/static) ANOVA was performed on these looking times. The results revealed no effect of the condition on the looking times [$F_{(2,33)} = 1.54$, $p = 0.2$, $\eta^2 = 0.9$]. Overall, newborns looked at the videos for an equal amount of time in each condition during the familiarization phase. No other effect or interaction was significant.

Facial Gesture Frequencies

The number of occurrences of facial gestures per second during the familiarization phase was analyzed. The average frequency of newborns' mouth movements was $M = 0.05$ ($SE = 0.002$) for the talking/silently condition, $M = 0.03$ ($SE = 0.002$) for the silently moving/silently moving condition, and $M = 0.05$ ($SE = 0.002$) for the talking/static condition. A three-way (condition: talking/silently moving, silently moving/silent, or talking/static) ANOVA was performed on the frequency of overall mouth movements. The results revealed no effect of condition [$F_{(2,33)} = 2.37$, $p = 0.11$, $\eta^2 = 0.13$]. Nevertheless, *post-hoc* analyses revealed than when comparing the familiarization conditions of both the talking faces to the silently moving face condition, newborns who looked at a talking face during the familiarization performed more mouth movements (M = 0.051, $SE = 0.003$) than those who looked at a silently moving face (M = 0.031, $SE = 0.002$) [$t_{(22)} = 1.83$, $p = 0.03$, Cohen's d = 0.7] (**Figure 3**).

Taken together, analysis of the looking times and the mouth movements during the familiarization phase evidenced a consistency in the visual attention of newborns when presented either with videos of talking faces or with a person looking at them silently. Nonetheless, it appears that they performed more mouth gestures in front of a talking vs. a silent face.

Test Phase

Visual Attention

The looking times (seconds) of newborns at the test in front of the familiar and the new face for each condition are presented in **Table 1**. As previously reported, newborns looked more at the familiar face only in the talking/static condition (Guellaï et al., 2011).

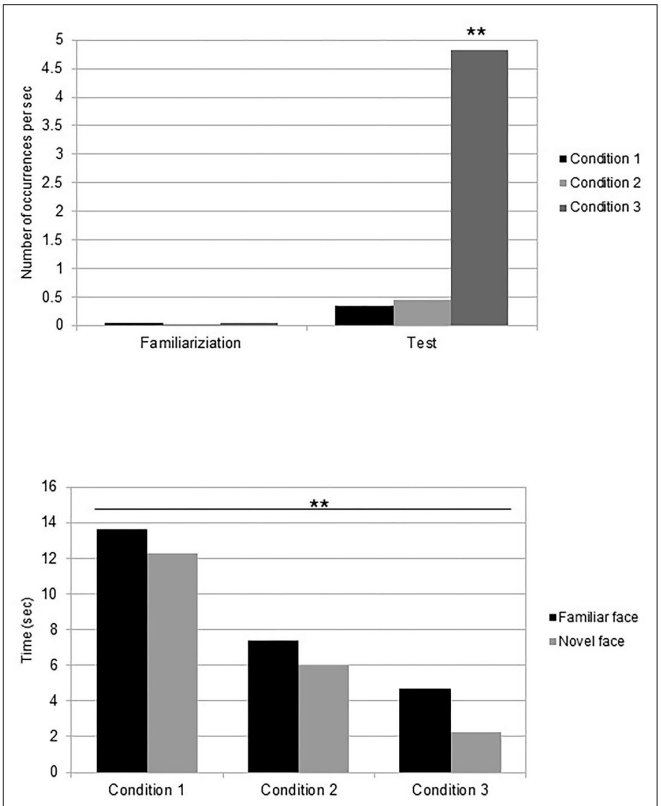

FIGURE 3 | Mean frequencies of mouth movements during the familiarization and test phases for each condition, and latencies of appearance of the first mouth movement in the test phase in front of the familiar and novel faces. $^{**}p < 0.05$.

TABLE 1 | Mean looking times in seconds in front of the familiar and new faces at test phase.

Condition 1		**Condition 2**		**Condition 3**	
Talking/ Silently moving		*Silently moving/ Silently moving*		*Talking/ Static*	
Familiar	**New**	**Familiar**	**New**	**Familiar**	**New**
30.3	32	29.7	33.8	** 40.6	22.7
(0.54)	(0.58)	(7.6)	(9)	(0.47)	(0.45)

Standard errors are indicated in brackets.
$^{**}p < 0.01$.

Frequencies of Mouth Movements

A 3 (condition: talking/silently moving, silently moving/silently moving, or talking/static) × 2 (familiarization face: blonde or brown-haired) × 2 (block of presentation: F1N1 or N1F1, F2N2 or N2F2) × 2 (test: blonde or brown-haired) ANOVA was performed on the overall frequencies with the two last factors within subjects. The analysis revealed a significant effect of the condition [$F_{(4,58)} = 3.69$, $p = 0.009$, $\eta^2 = 0.20$]. No other effect or interaction was significant.

Post-hoc analysis revealed that newborns in the talking/static condition performed more mouth movements ($M = 4.83$, SE

= 0.54) than those in the talking/silently moving condition [M = 0.33, SE = 0.04; $t_{(22)} = -2.4$, $p = 0.03$, Cohen's d = −0.8] and those in the silently moving/silently moving condition [M = 0.46, SE = 0.06; $t_{(22)} = 2.33$, $p = 0.03$, Cohen's d = 1]. No difference was observed between the two conditions with the silently moving face at test session [$t_{(22)} = -0.5$, $p = 0.62$, Cohen's d = −0.2] (**Figure 3**). Further analysis showed that the frequency of mouth movements was not different in front of the familiar face (M = 0.91, SE = 0.07) or in front of the novel one [M = 0.97, SE = 0.05, $t_{(35)} = -0.17$, $p = 0.87$, Cohen's d = −0.05] across conditions.

Finally, when comparing frequencies of mouth movements in the familiarization and test phases, newborns performed more mouth movements in the test phase than in the familiarization phase in the talking/silently moving [two-tailed t-test $t_{(11)} = 2.36$, $p = 0.038$, Cohen's d = 1.4] and in the talking/static [$t_{(11)} = 2.56$, $p = 0.026$, Cohen's d = 1.5] conditions, but not in the silently moving/silently moving condition [$t_{(11)} = 2.11$, $p = 0.06$, Cohen's d = 1.2] (**Figure 3**).

Reaction Times

The reaction time was defined as the delay between the appearance of the familiar or novel faces on the screen at the test and the appearance of the first mouth movement of the newborns. In front of the familiar face, newborns in the talking/silently moving condition realized their first mouth movement on average after 13.63 s (SE = 1.5), after 7.38 s (SE = 0.6) in the silently moving/silently moving condition, and in the talking/static condition it occurred after 4.67 s (SE = 0.7). In front of the novel face, newborns in the talking/silently moving condition realized their first mouth movement on average after 12.25 s (SE = 1.3), after 6.00 s (SE = 0.5) in the silently moving/silently moving condition, and in the talking/static condition it occurred after 2.25 s (SE = 0.4). We performed a 3 (condition: talking/silently moving, silently moving/silently moving, or talking/static) × 2 (familiar vs. novel face) ANOVA on reaction times at the test. The results revealed a significant effect of condition [$F_{(4,64)} = 3.80$, $p = 0.008$, $\eta_2 = 0.19$]. No other effect or interaction was significant (**Figure 3**). *Post-hoc* analysis evidenced that overall mouth movements appeared significantly quicker in the talking/static condition than in the other conditions [t-test, $t_{(11)} = 1.46$, $p = 0.04$, Cohen's d = 0.9].

DISCUSSION

The present study aimed at exploring the behavioral feedback of newborns in different interactive situations using videos of faces. Following studies on neonatal imitation, mouth movements were analyzed as possible indicators of communicative behaviors. More precisely, we expected newborns' occurrences of mouth movements to differ according to the different conditions: (a) whether or not the person in front of them was talking and (b) if the person had been already seen or was a new one.

Overall, our results show that the context of presentation of a potential social partner affects the gesture rates and latencies of infants, suggesting that newborns are already sensitive to the conditions of presentation of unfamiliar faces. More precisely, newborns produced more mouth movements in front of someone who was talking to them rather than someone looking at them silently moving. Besides, they produced more mouth movements following familiarization with a talking vs. a silent face. In other words, this first result shows that a talking face elicits more motor feedback from the newborns than a silent face. This extends results of previous studies showing that the production of specific mouth movements by newborns occurred more in front of congruent audiovisual presentations of faces than incongruent ones (Chen et al., 2004; Coulon et al., 2013). Nonetheless, whereas in the past studies, faces were repeating the same speech sound (i.e., a vowel or a consonant), in the present study, we presented continuously talking faces closer to real-life situations. It is therefore possible that verbal interactive situations are favorable to eliciting what could be seen as precursors of communicative actions in the neonatal period (Trevarthen, 1998; Dominguez et al., 2016).

Moreover, our results did not evidence a difference in the behaviors of newborns in front of the familiar face or the novel one. Therefore, soon after birth, infants do not appear to use imitation for the purpose of identifying social partners. This result is surprising as previous work on imitation has associated neonates' production (and reproduction) of mouth movements as indicators of social partner recognition (Meltzoff and Moore, 1994; Meltzoff et al., 2018; Nagy et al., 2020). Nonetheless, previous studies did not use the familiarity–novelty procedure as they presented either the familiar face (i.e., the mother) or the stranger's one during a unique interactive test period. To our knowledge, only one study used the familiarity–novelty procedure to explore the imitation of non-human primate neonates (Simpson et al., 2013). Results evidenced that rhesus macaques in the first week of life do not appear to produce more mouth movements in front of a familiar or a novel face. Here, in the talking/ static condition, newborns' visual attention and their motor feedback do not have the same pattern of results. Whereas visual attention indicates a preference for the familiar face, motor feedback does not. This suggests that considering different types of dependent variables may be complementary and useful for a better understanding of the infants' behavior, particularly in the studies on newborns. Further studies with a more systematic analysis of the complementary dependent variables should be conducted in the future.

Finally, when comparing newborns' production of mouth movements during the test phase, different results were revealed. First, it appeared that frequencies of mouth movements were greater in the test phase than during the familiarization phase. This could be explained by the fact that a delay is usually observed in the neonatal motor feedback with mouth movements appearing after the face began producing it (Coulon et al., 2013). Second, frequencies of mouth movements were greater, and latencies of appearance of the first movement were shorter, in front of a static vs. a dynamic face. This latter result could be interpreted as evidence of newborns' ability to discriminate between photographs and videos of faces similar to that observed in older infants (Hunnius and Geuze, 2004). Our results have also

some parallels with previous studies using the still-face paradigm (Tronick et al., 1979). In this paradigm, a normal face-to-face interaction between an infant and an adult is interspersed with a period in which the adult suddenly becomes unresponsive and poses a stationary neutral face while maintaining eye contact. Infants as young as 2 months of age react to the adults' unresponsiveness during the still-face period with decreased visual attention and positive affect. Such results are interpreted in terms of infants' affective attunement to social patterns and rudimentary expectations about the nature of face-to-face interactions. Some studies using this paradigm with younger infants did not find any difference in the infants' reaction in front of an interactive or a static face (Bertin and Striano, 2006). This latter result is different from that observed in the present study. A possibility is that in the previously cited study, the authors analyzed the gaze and smiles of newborns, whereas here we analyzed a broader range of mouth movements replicating those investigated in the imitation studies. A possible explanation for the greater frequencies of newborns' mouth movements observed in front of a static face compared to a dynamic one could be that infants are trying to make the face react. Another possibility is that attention to the face is enhanced when the person is talking, which would attract newborns' attention and therefore would lead to less orofacial movements. Indeed, some studies evidenced that multimodal presentation enhances attention in very young infants (Spelke, 1976).

To conclude, the results of the present study are congruent with the idea of the existence of precursors of effective and positive interactions as soon as birth. Further work is needed to explore the development of infants' feedback in different interactive situations, as this could have important implications for neonatal care units.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by CER Paris Nanterre. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

BG collected and analyzed data. BG and AS wrote article. Both authors contributed to the article and approved the submitted version.

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Intersubjectivity as an antidote to stress: Using dyadic active inference model of intersubjectivity to predict the efficacy of parenting interventions in reducing stress—through the lens of dependent origination in Buddhist Madhyamaka philosophy

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Intersubjectivity refers to one person's awareness in relation to another person's awareness. It is key to well-being and human development. From infancy to adulthood, human interactions ceaselessly contribute to the flourishing or impairment of intersubjectivity. In this work, we first describe intersubjectivity as a hallmark of quality dyadic processes. Then, using parent-child relationship as an example, we propose a dyadic active inference model to elucidate an inverse relation between stress and intersubjectivity. We postulate that impaired intersubjectivity is a manifestation of underlying problems of deficient relational benevolence, misattributing another person's intentions (over-mentalizing), and neglecting the effects of one's own actions on the other person (under-coupling). These problems can exacerbate stress due to excessive variational free energy in a person's active inference engine when that person feels threatened and holds on to his/her invalid (mis)beliefs. In support of this dyadic model, we briefly describe relevant neuroimaging literature to elucidate brain networks underlying the effects of an intersubjectivity-oriented parenting intervention on parenting stress. Using the active inference dyadic model, we identified critical interventional

strategies necessary to rectify these problems and hereby developed a coding system in reference to these strategies. In a theory-guided quantitative review, we used this coding system to code 35 clinical trials of parenting interventions published between 2016 and 2020, based on PubMed database, to predict their efficacy for reducing parenting stress. The results of this theory-guided analysis corroborated our hypothesis that parenting intervention can effectively reduce parenting stress if the intervention is designed to mitigate the problems of deficient relational benevolence, under-coupling, and over-mentalizing. We integrated our work with several dyadic concepts identified in the literature. Finally, inspired by Arya Nagarjuna's Buddhist Madhyamaka Philosophy, we described abstract expressions of Dependent Origination as a relational worldview to reflect on the normality, impairment, and rehabilitation of intersubjectivity.

KEYWORDS

intersubjectivity, parenting stress, relational worldview, free energy principle, parent-child dyadic interaction, dependent origination (pratītyasamutpāda), emptiness (Śūnyatā), maternal sensitivity

Introduction

> *The world is not an aggregation of things, but rather a symphony of relationships between many participants that are altered by the interaction.*
>
> (Weber, 2017, p. 29)

An emerging view of evolution suggests that evolution of living systems is about survival-of-the-fitted—those entities that resist entropic destruction—rather than survival-of-the-fittest—the entities with the greatest reproductive success (Cohen and Marron, 2020). That is, survival requires a living entity to be integrated within biological and material networks to convert entropic disorganization into organization amid universal properties of energy, entropy, and interactions (Schrodinger, 2012; Friston, 2013; Ramstead et al., 2018). All biological substances, from a molecule to an organism, become what they are by interacting with something else in the environments (Gilbert et al., 2015) and they are impermanent as they become something different after each and every interaction with other objects (Weber, 2017). In short, living organisms are impermanent, inter-dependent, self-organizing systems in a universe of energy, entropy, and interactions.

As living systems are more appropriately considered as symbionts in symbiosis, as opposed to independent "individuals" existing in and of itself (Gilbert et al., 2012), human beings are no exception. The dyadic interactions between mother and infant constitute a prime example of inter dependence. Indeed, bidirectional moment-to-moment interactions between the symbionts, e.g., a mother and an infant, have long been recognized as important for infant development by developmental psychologists, e.g., (Bowlby, 1969; Stern, 1971; Sander, 1977; Tronick et al., 1978; Beebe and Lachmann, 1998). Recently, a systematic review has parsed the literature on mother-infant interactions in terms of nine dyadic concepts, namely, Mutuality, Reciprocity, Attunement, Contingency, Coordination, Matching, Mirroring, Reparation, and Synchrony (Provenzi et al., 2018), which will be described later. While these dyadic concepts are known to exert multiple effects on the developments of IQ, conduct, secure attachment, and stress regulation (Provenzi et al., 2018), they are not yet integrated in a formal theoretical framework (such as an active inference framework to be described in this paper), despite the well-known emphasis of dyadic interactions in many developmental theories, e.g., (Stern, 1971; Sander, 1977; Tronick et al., 1978; Beebe and Lachmann, 1998). Partly due to the lack of such integration, very little is known about the effects of engaging in dyadic interactions on maternal health and well-being, as acknowledged by Provenzi et al. (2018).

In this paper, we aim to address the gaps between these concepts in parent-child relations and a formal dyadic model that can provide heuristics for therapeutic interventions to promote the wellbeing of mother-child dyad. First, we postulate that intersubjectivity is a hallmark of quality dyadic interactions. Second, we introduce an active inference framework, namely, Free Energy Principle (FEP), to describe a person in a weakly coupled state and then propose our own dyadic active inference model to model dyadic interactions in a strongly coupled state, such that the causal link between intersubjectivity and maternal wellbeing (specifically, the reduction of parenting stress) is established. Third, we describe how maternal

intersubjectivity can be impaired by problems of deficient relational benevolence, under-coupling, and over-mentalizing, with brain-based evidence for our theory. Fourth, to further corroborate our theory, we present a theory-driven literature review, using a coding system derived from our dyadic model to code recent clinically studied parenting interventions that measured parenting stress index (PSI; Abidin, 1995) as one of the outcome variables. Fifth, we integrate our work with the literature of dyadic concepts, using the meta-analytical review by Provenzi et al. (2018). Finally, inspired by Buddhist Madhyamaka Philosophy, championed by Arya Nagarjuna (ca 150–250 CE), we describe a relational worldview in terms of an abstract expression of Dependent Origination. By applying this abstract expression of Dependent Origination to the domains of physics, awareness, intersubjectivity, and active inference, we wish to elucidate a profound relation between intersubjectivity and wellbeing, i.e., intersubjectivity is anti-stress.

Intersubjectivity is a hallmark of quality dyadic interactions and wellbeing

> *The acid test of every epistemology is, when all is said and done, the intersubjective relationship.*
>
> (Fuchs, 2017, p. 27)

Intersubjectivity—the relation between subjects—has been a key concept in phenomenology (Zahavi, 2018). When referring specifically to *the awareness of others' awareness*, intersubjectivity is synonymous to some definitions of empathy in psychology (Preston and Hofelich, 2012; Zahavi and Overgaard, 2013). The wellbeing of the child can be influenced by the mother-child dyadic interactions, and the quality of these dyadic interactions is directly related to the capacity of maternal intersubjectivity (Leerkes et al., 2009), which is also known as parental sensitivity (Ainsworth et al., 1978; Bernard et al., 2013), parental empathic attunement (Rowe and MacIsaac, 2004), parental reflective functioning (Fonagy et al., 1991; Slade, 2005), and parental embodied mentalizing (Shai and Belsky, 2011). Poor quality in parent-child interactions can cause chronic stress in children and consequently resulting in multiple physical and mental health problems that surface later in life (Shonkoff et al., 2012). Not surprisingly, the capacity of maternal intersubjectivity is also related to maternal wellbeing. The capacity of intersubjectivity can be compromised in mothers suffering from interpersonal aggression (Dayton et al., 2016) and depressive mood disorders (Bernard et al., 2018), leaving these mothers at risk for excessive parenting stress, as parenting stress is inversely associated with parental intersubjectivity (Shai et al., 2017). Impaired parental intersubjectivity can adversely affect the bonding with the spouse as well (Nakić Radoš, 2021). Fortunately, the impairment of maternal intersubjectivity can be reversed. For example, we reported that a parenting intervention that increased the capacity of maternal intersubjectivity can reduce parenting stress with concomitant changes in the maternal brain regions that are known to mediate intersubjectivity (Ho et al., 2020).

The development of intersubjectivity in infants has been studied empirically since 1970's. Among the pioneers, Colwyn Trevarthen and colleagues postulated the theory of "innate intersubjectivity" to account for the ontogeny of the active "self-and-other" awareness, stating that "*the infant is born with awareness specifically receptive to subjective states in other persons*," and that a human being "*grows in active engagement with an environment of human factors – organic at first, then psychological or inter-mental*." (Trevarthen, 1974; Trevarthen and Aitken, 2001). Trevarthen and Aitken (2001) suggested that intersubjectivity is as innate as *intrinsic motive formations* (IMFs) underlying three types of engagements with the world: (1) a "self-unity" that is innate and maintained by organismic self-organizing processes (IMFs) that regulate the physiological functions of the body to maintain a person's self; (2) an agency that is developed to possess anticipatory control over the effects of actions and perceptions of objects in the environments; and (3) an inter-mental awareness (awareness of others' purposes) that is developed through communications with other persons and dynamic interactive adjustments to others' behaviors.

Toward a dyadic model for intersubjectivity

Since infancy, we live our lives alternating between a weakly coupled state, in which we are not interacting with the environments, and a strongly coupled state, in which we are intimately interacting with others, e.g., moments of parent-infant interactions. In the science of complexity, the weakly coupled and strongly coupled states instantiate different phases of a complex system. In general, phase transitions produce discontinuity in the thermodynamic free energy of a complex system, such that a simple behavior in one phase may give rise to tremendous complexity in the other phase (Cocchi et al., 2017). Though the body of literature in complex systems is huge, here we only focus on the use of active inference framework to heuristically model a person in two phases separately—a weakly coupled state and a strongly coupled states—as follows.

An active inference model in a weakly coupled state

The active inference framework is based on the premises that (1) perception and action of a person self-organize to

minimize a quantity known as variational free energy and that (2) action selection, planning, and decision-making can be optimized by minimizing expected free energy, which quantifies the variational free energy of various actions based on expected future outcomes (Smith et al., 2022). Infants are born with self-unity that serves as a seed (ground zero) within innate complex self-organizing processes, as if they are objective perceivers and actors that are differentiated from other entities (Rochat, 2019). Such innate self-unity can serve as a seed (prior) in the active inference framework (Friston, 2018).

According to FEP, a living organism is a self-organizing system that maintains its characteristic phenotypic states and avoids surprising deviations from these expected states by generative processes that are self-organizing and self-evidencing. As the physical, biological processes of an organism embody its "best guess" about its environments, on average and over time the organism tends be attracted to a limited number of attractor states in the space of all possible states, with low entropy or spread in the probability density over the space of possible states, i.e., low variational free energy. Variational free energy is a measure of the upper bound of surprise or prediction error—the difference between the organism's "best guess" beliefs about what caused its sensory states and what it observes (Friston, 2013; Ramstead et al., 2020; Friston et al., 2022).

Free energy principle adopts the notion of Markov blankets to define the boundary of the living system and its environments—which are partitioned as internal (systemic) states and external (environmental) states, respectively. The Markov blanket itself can be partitioned into active and sensory states, which can be differentiated as follows: active states are not influenced by external states, and sensory states are not influenced by internal states (Friston, 2013; Ramstead et al., 2018, 2020). The internal states and its Markov blanket together constitute an active inference engine that actively self-organizes to stay in the most probable expected states, i.e., the living system's characteristic phenotypes.

Here we briefly describe the concept of Markov blanket as prescribed in FEP (Parr et al., 2022). Technically, a Markov blanket (b) is defined as follows:

$$p(\mu, x|b) = p(\mu \,|b)p(x|\, b)$$

This says that, statistically speaking, if b is known, then a variable μ is conditionally independent of a variable x. In other words, if knowing the values of x and μ both depends on the condition of knowing the value of b, then knowing x would give us no additional information about μ. To identify a Markov blanket in a system with conditional dependence, one can follow a rule that the blanket for a given variable comprises its *parents* (the variables it depends on), its *children* (the variables that depend on it) and, in some settings, the other *parents of its children*.

The FEP leverages the principle of minimizing variational free energy—the upper bound of surprise or prediction errors—to optimize the prior beliefs in the active inference engine. There are two ways to minimize variational free energy, i.e., perceptual inference and active inference. In perceptual inference, agents strive to update their prior beliefs, while in active inference agents change their environment (or their sampling of information from the environment) by selecting a plan or policy in a set of prior beliefs that would yield the least expected free energy (Peters et al., 2017). Notably, in FEP, the variational free energy is more of a function of beliefs and expectations in the internal states rather than a function of the environments hidden from the internal states (Ramstead et al., 2020). In such processes, internal and active states' dynamics are a function of, and only of, a variational free energy bound on surprise, and the belief optimization is implicitly done in the minimization of variational and expected free energy (Friston et al., 2022).

The notion of active inference emphasizes that actions solicit a sensory outcome that informs approximate posterior beliefs about external states of the world. Such generative process in FEP renders a living organism to be participatory, or enactive in soliciting and therefore co-creating its perception of the external states, which is very different from a representationalist process by which external states generate sensory states exclusively (Friston et al., 2022). Heuristically, one may consider that an active inference engine is actively self-evidencing what the world should be (known as an enactive account), rather than passively learning to represent what the world seems to be (known as a representationalist account)—a distinction that has been elaborated in the literature (Ramstead et al., 2020). How this distinction is related to the differences in two incompatible worldviews will be clarified later.

Inspired by FEP (Friston, 2013), we suggest that a person can be formally modeled as an active inference engine in a multi-level network consisting of four nodes, namely nodes of sensory states (S), active states (A), internal states (I), and external states or events (E). This network is partitioned into an external state (E) and an active inference engine that consists of the nodes (S) and (A) at a lower level and node (I) at a higher level. See **Figure 1**. The internal state (I) can be conceived as an innate prior—a set of "best guess" beliefs that may guide the active inference engine's action planning and selection. When an event in the external states (E) interacts with a person, it can only affect internal states (I) indirectly through its interaction with the Markov blanket nodes (A) and (S), such that (E) afferently causes (S) to change and (A) efferently causes (E) to change; On the other hand, the nodes (S) and (A) at the lower level interact with the person's prior beliefs in internal states (I) at the higher level, such that (S) causes (I) to change and (I) causes (A) to change.

In this model, nodes (A) and (S) are the Markov blanket of the node (E), because (A) is a *parent* of (E)—because (E)

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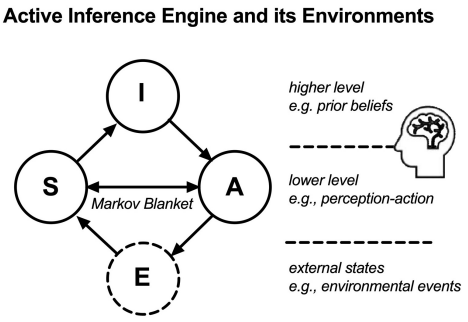

FIGURE 1
An active inference and its environments (external states): In an active inference model, an adaptive person functions as an active inference engine—consisting of nodes (A), (S), and (I; solid circles). In a hierarchical network, (S) represents the person's afferent sensory state and (A) represents the person's efferent active state, both at a lower level, and (I) represents the person's prior beliefs at a higher level. Node (E) represents environmental events as external states (dashed circle). The bidirectional arrowed line between (A) and (S) indicates the notion of active inference, that actions solicit a sensory outcome that informs approximate posterior beliefs in the internal states (I) about the external states (E). This is done by minimizing variational free energy—the upper bound of surprise or prediction errors of the active inference. Nodes (E) and (I) do not have direct effects on one another, as they are separated by nodes (A) and (S) that serve as Markov blanket. Nodes (I) and (E) are statistically independent of each other given the Markov blanket, nodes (A) and (S). That is, the nodes (I) and (E) maintain a conditional independence of each other in the model, such that if the values of the Markov blanket nodes (S and A) are known, then knowing the internal states (I) does not provide any additional information about the external states (E), and *vice versa*. This conditional independence may give rise to the appearance of duality between the subject (the active inference engine) and the object (the external states) and is therefore considered a hallmark of a weakly coupled state of the active inference engine.

depends on (A)—and (S) is a *child* of (E)—because (S) depends on (E). In contrary, node (I) is not the Markov blanket of (E) because (I) is neither a *parent* or *child* of (E), nor another parent of (E)'s child, (S). In this system, nodes (I) and (E) are conditionally independent of each other, under the condition of knowing the Markov blanket nodes (A) and (S). Conditioned on the Markov blanket, i.e., sensory states (S) and active states (A), the prior beliefs activated in internal states do not provide any additional information about the external state, (E), due to the conditional independence between nodes (I) and (E), as follows,

$$p(\mathrm{I} \cap \mathrm{E}|b) = p\left(\mathrm{I}|b\right) p\left(E|b\right) \text{ wherein } b \text{ refers to Markov blanket nodes (S) and (A)}$$

Due to the conditional independence between nodes (I) and (E), the active inference engine and its external states are in a weakly coupled (conditionally independent) state, giving rise to the apparent duality between subject (the observer) and object (the observed), because knowing the former does not provide any information about the latter, and *vice versa*.

A dyadic active inference model in a strongly coupled state

We need a dyadic model of two agents that are strongly coupled to model intersubjectivity that arises from subject-subject interactions. Just like ice and water are two phases of the same H_2O molecules that behave distinctly (solid and liquid, respectively), the same active inference engine can behave very differently between the phases of weakly coupled and strongly coupled states—while an active inference engine maintains conditional independence between its internal and external states in a weakly coupled state, such conditional independence is diminished in a strongly coupled state, when its external states are no longer a unitary node (E), but rather another active inference engine, such that one engine's active states (A) serve as a parent of the other engine's sensory states (S), and *vice versa*. In the most strongly coupled state, one person's active states will become total environmental inputs for the other person's sensory states, and *vice versa*.

Assuming this strongly coupled state in parent-child relationship, we have published a dyadic model to account for the inverse relationship between stress and intersubjectivity (Ho et al., 2020), wherein we studied how parental intersubjectivity is embodied and enacted in the brain. In this dyadic active inference model, when two active engines (two persons, say mother as Person 1 and child as Person 2) are strongly coupled, such that mother's active state (A_M) causes child's sensory state (S_C) and child's active state (A_C) causes mother's sensory state (S_M), one's A and S become progressively similar to the other's (A) and (S), respectively, over time, and prior beliefs in their internal states (Is) are hence attuned. Under such strong coupling, the two persons are actively inferring the other's intentions in their prior beliefs hidden behind the sensory and active states and the variational free energy in the dyad is yoked as well. Thus, the strong coupling state mandates that one person's prior beliefs about the other's prior beliefs cannot reach the minimal variational free energy unless the other's prior beliefs of the one's prior beliefs also reach the minimal variational free energy—In other words, a higher level of intersubjectivity is attained if and only if the variational free energy in this strongly coupled state is minimized collectively. See **Figure 2**.

The root of the impairment of intersubjectivity

The dyadic model of intersubjectivity that we proposed can explain why a child naturally wants to be mirrored and loved by the parent and will feel abandoned by an insensitive parent who neglects or dismisses this natural desire. Indeed, the relational benevolence—love and warmth for another person's

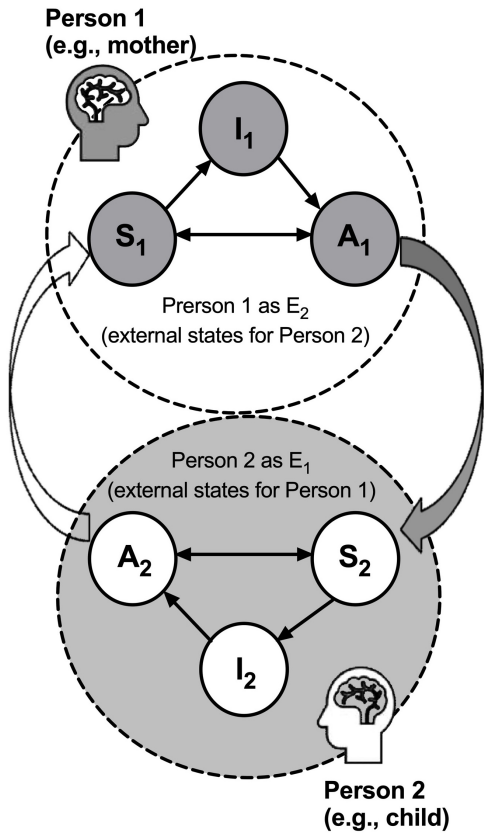

FIGURE 2
Active inference model in a strongly coupled state: When two persons (mother as Person 1 and child as Person 2) are strongly coupled, one person's active states become the total environmental inputs for the other person's sensory states, and *vice versa*. In this dyadic model, the strong coupling between the two persons is formed when their nodes (As) and (Ss) are coupled, wherein (A_1) causes (S_2) and (A_2) causes (S_1). Due to the strong coupling, the variational free energy in Persons 1 and 2 are also coupled and thus the prior beliefs in their internal states (I_1 and I_2) are optimized collectively. The two large, dashed circles indicate that there are no longer any unitary nodes (E) in the dyadic model, as the external states are now served by the multi-level network of the other person's active inference engine.

sake—in dyadic interactions has begun to be recognized to play a critical role in wellbeing (Maté, 2012). Unfortunately, not all parents are equal in their capacity of relational benevolence and intersubjectivity.

> *But how come one can hold on to an invalid prior belief for so long, despite the excessive stress that renders his or her life miserable?*

Evidently, it is possible for humans to hold on to an outdated, invalid (mis)belief to the extent of becoming pathological, which is equivalent to keeping an overweighted prior in one's active inference engine (Carhart-Harris and Friston, 2019). If a person fails to update or replace an outdated invalid belief, it may result in excessive variational free energy, and hence excessive stress (Peters et al., 2017; Goekoop and de Kleijn, 2021).

The misery of obsessively holding on to an invalid prior belief may be impossible for artificial intelligence (AI) programs—which can be considered as non-human inference engines (Friston et al., 2022)—because AI programs' prior can be updated or replaced anew millions of times a day, without any stress or misery, such that they perform superbly, sometimes even outperform human champions, without any human assistance in games like chess, shougi, or go (Silver et al., 2017a,b).

We have postulated, in contrast to the AI programs, people suffer needlessly when they have invalid beliefs that do not reflect the reality, because invalid beliefs can cause human active inference engines to malfunction (Ho and Nakamura, 2017; Ho et al., 2021). The rehabilitation of impaired intersubjectivity is central to Indo-Tibetan Buddhist practices (Wallace, 2001). Informed by the central doctrines of Buddhism (Tenzin Gyatso, 1997, 2009), we specifically postulated (Ho et al., 2021) that the invalid beliefs that can cause the malfunctioning of active inference engines are called conceptual thoughts (*Vikalpas* in Sanskrit) that are laden with a non-relational view that there is a constant unchanging entity that is not changed by interactions and that an entity's ultimate nature is identical to something observable (i.e., realism); and these invalid beliefs can be proliferated and embodied through processes called mental fabrication or superimposition (Prapañca in Sanskrit; Asanga, 2016).

In other words, we postulated that when a normal active inference engine is inflicted with non-relational prior beliefs (*Vikalpas*) in its internal states, which are invalid because they do not reflect the reality that all phenomena are products of subject-by-object interactions, the process of mental fabrication (Prapañca) will impair the active inference engine by holding on to invalid beliefs in the internal states, node (I), despite its failure to minimize variational free energy. We will discuss these Buddhist notions in the context of relational worldview to be presented later.

In accordance with our postulation, we have theorized a dyadic model to explain the inverse relationship between parenting stress and maternal intersubjectivity and identified key brain regions that may mediate this relationship using a pre- and post-test design with the evidence-based "Mom Power" parenting intervention (Ho et al., 2020). In that report, we have identified three inter-related relational issues that may be addressed by dyadic interventions to reduce stress in dyadic interactions, namely, the problems of *(1) deficient relational benevolence due to invalid beliefs, (2) under-coupling, and (3) over-mentalizing*, as follows:

1. *Deficient relational benevolence:* Invalid beliefs prevents the awareness of relational benevolence, e.g., maternal empathic love and warmth toward the child's internal states in the current context. When two persons (e.g., mother and child) are strongly coupled ($\mathbf{A}_{mother} \approx \mathbf{S}_{child}$ and $\mathbf{A}_{child} \approx \mathbf{S}_{mother}$), the variational free energy are minimized collectively *if*, and *only if*, the prediction error in one person is minimized without increasing the other's. Therefore, mother can achieve intersubjectivity by minimizing her variational free energy through communicative interactions with child, wherein mother's prior belief would approximate child's prior beliefs ($\mathbf{I}_{mother} \approx \mathbf{I}_{child}$). We have postulated that invalid beliefs (*Vikalpas*) will obscure the awareness of interdependence, and hence may diminish the awareness of relational benevolence and of the prior beliefs of each person's active inference engine (Ho et al., 2021).
2. *Problem of under-coupling:* Under-coupling increases variational free energy. As depicted in **Figure 3**, when Person 1 engages Person 2's overt behaviors only, Person 1 may reduce Person 2, who serves as Person 1's external states, to a unitary object without its own inner states such as feelings and prior beliefs. Thus Person 1 would fail to achieve intersubjectivity and find it difficult to reduce stress in either party. For example, when mother neglects to see that her harsh reactions cause the child to feel negatively and only focuses on how to change child's behaviors, mother would fail to recognize child's attempts to reduce child's own variational free energy and therefore mother's variational free energy during dyadic interactions would increase. Being ignored or rejected, child's stress (excessive variational free energy) would increase, which would, in return, increase mother's stress.
3. *Problem of over-mentalizing*: Over-mentalizing can perpetuate impairments of intersubjectivity and exacerbate dyadic stress. When there is a disagreement or conflict between two persons, dyadic stress may increase if person 1 becomes defensive against person 2, as if person 2 were an enemy, and therefore misattributing person 2's disagreeing behaviors to malice or character flaw, i.e., over-mentalizing. For example, mother may over-mentalize child's behaviors as "he does not respect me." When mother's over-mentalizing explains away child's actual prior belief, she will not even recognize her own ignorance of child's feelings and prior beliefs. Thus, when stress potentiates mother's over-mentalizing, child's disagreeing behaviors would only confirm mother's preconceived existing biases against child, perpetuating the impairment of intersubjectivity in a vicious cycle. As described later, conceptual thoughts are responsible for the problem of over-mentalizing. As depicted in **Figure 3**, Imaginary E_1 (in a dashed circle) denotes Person 1's conceptual thoughts that may result in Person 1's over-mentalization of Person

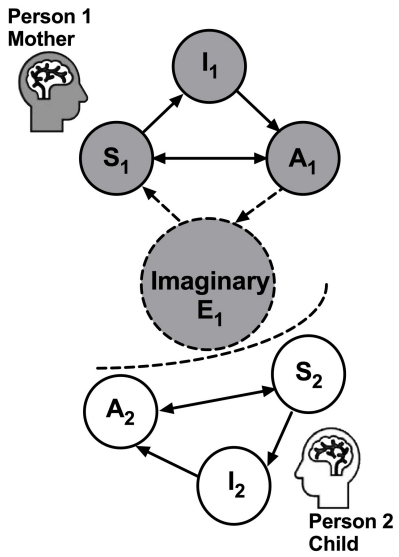

FIGURE 3
Under-coupling and over-mentalizing problems ensue in a dyadic system when Person 1 discards Person 2's active inference engine and instead reduces Person 2 to an imaginary concept, namely Imaginary E_1, as if it were a node E in a weakly coupled state, as denoted in the dashed circle in the center. Such imaginary E_1 is therefore responsible for Person 1's over-mentalization of Person 2. The dashed curve between Person 1 and Person 2 indicates the under-coupling, when Person 1 tends to ignore Person 2's attempts to minimize variational free energy and instead treat Person 2 as an object in Person 1's conceptual thoughts. The dashed arrows to and from Imaginary E_1 indicate the lack of actual generative processes to minimize variational free energy in this pathological state.

2. The dashed curve between Person 1 and Person 2 indicates the under-coupling, when Person 1 tends to ignore Person 2's attempts to minimize variational free energy and instead treat Person 2 as an imaginary object in Person 1's conceptual thoughts. The dashed arrows to and from Imaginary E_1 indicate the lack of actual generative processes to minimize variational free energy in this pathological state.

A brain model for intersubjectivity as a therapeutic target of parenting intervention

There is now preliminary neuroimaging support for brain networks that may mediate the effects of a parenting intervention on maternal intersubjectivity (Ho et al., 2021). In this study, we assigned mothers to "Mom Power" intervention or a control condition and all of them underwent a child face

mirroring task (CFMT), at pre-treatment and post-treatment (Ho et al., 2020). The CFMT was designed to elicit maternal intersubjectivity-dependent responses to their own children or unknown other's children by asking the participants to imitate children's emotional facial expressions or a control condition (simply observe without imitating), because voluntary imitation of others' facial expressions is key to the development of intersubjectivity (Meltzoff and Moore, 1977). The results showed that the within-subject changes in parenting stress were positively associated with the concurrent changes in the differential responses during prediction error-related (positive vs. negative valence) contrast in the imitating (mirroring) own child's faces vs. its control condition in the periaqueductal gray (PAG), a subcortical region related to fight-or-flight defensive motivation, and, conversely, negatively associated with those in the amygdala and nucleus accumbens (NAc), two subcortical regions related to social reward motivation. Moreover, the within-subject changes in parenting stress were positively associated with the functional connectivity between the dorsomedial prefrontal cortex (dmPFC) and PAG, and, conversely, negatively associated with concurrent changes in the functional connectivity between dmPFC and NAc, during the imitating (mirroring) own child's faces vs. its control condition. Connectivity with the dmPFC may be interpreted in relation to at least two functions: (1) social mirroring behaviors and (2) representing the significant other (Ho and Nakamura, 2017). The parenting intervention effects on stress reduction were partially mediated by differential changes in subcortical functional connectivity in maternal brain regions of NAc and PAG, which have also, respectively, been associated with maternal care vs. defense, respectively, (Numan, 2007; Swain et al., 2018). Notably, brain regions underlying surprise or deviation from expectation largely overlap with these subcortical motivational neurocircuits, including the amygdala, NAc, and PAG (Swain and Ho, 2017). Additionally, this model has been important in the interpretation of the differential effects of opioids on the maternal brain, which include disrupted connectivity between NAc and PAG (Swain and Ho, 2021).

The provisional success in identifying a brain model to support the dyadic active inference model encouraged us to conduct the following theory-guided analysis of published intervention studies.

A theory-guided quantitative analysis of parenting intervention studies in the literature

> *When the rose is gone and the garden faded*
> *you will no longer hear the nightingale's song.*
> *The Beloved is all; the lover just a veil.*
> *The Beloved is living; the lover a dead thing.*
> *If love withholds its strengthening care,*
> *the lover is left like a bird without care,*
> *the lover is left like a bird without wings.*
> *How will I be awake and aware*
> *if the light of the Beloved is absent?*
> *Love wills that this Word be brought forth.*
>
> Jalaluddin Rumi (Mathnawi I, 23–31)

Using Rumi's poem as a metaphor, when primary caregivers are somehow laden with the problems of *deficient relational benevolence, under-coupling, or over-mentalizing*, the "garden" in which a child can thrive is faded, and the child is like a bird without wings. As described above, we postulate that parenting stress will mostly result from dysfunction of interaction processes associated with the three relational issues that we deduced based on the dyadic active inference model of intersubjectivity.

Accordingly, we hypothesize that a parenting intervention should effectively reduce parenting stress if the intervention is designed to address these three issues by promoting relational benevolence and by training the skills to mitigate the under-coupling and over-mentalizing problems in parents. To test this hypothesis, we conducted a theory-guided quantitative analysis of recently published studies of parenting intervention by developing a coding system to parse parenting interventions published between year 2016 and 2020 and examined whether results based on the coding were associated with the effects of parenting interventions, as compared to a control or baseline condition, on PSI, one of the most common measures of parenting stress (Abidin, 1995).

Methods of the theory-guided quantitative analysis

We used PubMed database to search for randomized controlled trials (RCTs) reported in English in the last 5 years prior to January 14, 2021, using the following keywords: "Parenting intervention," "RCT" or "randomized controlled trial," and "PSI." We found 52 studies that met inclusion criteria and screened out 17 of them due to the following reasons: (1) the lack of PSI total score as an outcome variable, (2) the absence of comparisons between a intervention condition and a control/baseline condition, or (3) the presence of a medical condition, e.g., traumatic brain injury in the child, that may originate from and/or result in complications in the social environments beyond the parent-child dyads. The list of the final 35 studies reviewed and the coding results for each study are presented in **Table 1**. These studies were

coded by two authors SSH and MG (hereafter Raters 1 and 2, respectively) independently, according to the following binary coding scheme.

1. To meet Component 1 (promotion of relational benevolence through enhancing awareness of the child's internal states and the importance of love and warmth in dyadic interactions), a treatment (Tx) should have ALL of the following: 1. Specific own child in question; 2. Education on child's social developmental needs, including the development of secure attachment in the child's prior beliefs, which are only made possible through dyadic interactions; and 3. Emphasize the importance of the caregiver's positive stance, e.g., warmth, love, sensitivity, etc.
2. To meet Component 2 (intervention to reduce under-coupling), a Tx should have ALL of the following: 1. Asking the parent to realistically observe the child's behaviors, with sufficient consistency with what another observer would agree, i.e., valid observation; 2. Education of behavioral techniques contingent on actual feedback from the child's response during parent-child interactions.
3. To meet Component 3 (intervention to reduce over-mentalizing), a Tx should have ALL of the following: 1. Skill training on how to observe one's thoughts and feelings with non-judgmental stance, without necessarily reacting to thoughts and feelings, e.g., mindfulness; 2. Education on how one's moods and beliefs may negatively influence one's projection/mentalizing of others and may increase distress tolerance when parents are in negative moods, e.g., feeling frustration.

The Components 1–3 in the coding scheme corresponded to the three components of the dyadic active inference model, which we developed and presented above to address the problems of *(1) deficient relational benevolence, (2) under-coupling, and (3) over-mentalizing*, respectively. Notably, the major distinction between Component 1 and other Components is that Component 1 serves as a mindset, a frame centered in the dyad, not a single person, with an emphasis on unconditional positive regards, e.g., love and warmth, of the relation, while Components 2 and 3 are more specifically contingent upon specific situations and skill oriented. The major distinction between Components 2 and 3 is that Component 2 should be focused on child-oriented observations with a data-driven approach, not inward observations of parents' internal working model of the child. Conversely, Component 3 should be focused on parental inward-observations of parental thoughts and emotions when they are used to mentalize the child.

The outcome variable, the Tx effect on PSI, was coded according to the following rule: If there was a statistical significant difference in PSI (total score) between the intervention (Tx) and Control groups, as a significant Group main effect or a Time-by-Group interaction effect, or a within-subject difference from a baseline, such that the PSI total score was lower in the Tx than the control condition, then the Tx effects of PSI was coded as "1" (positive effect), otherwise as "0" (negative effect).

Results of the theory-guided quantitative analysis

Inter-rater reliability

The coding of Components 1–3 showed superb inter-rater reliability between the two raters. For Component 1, Rater 1 coded 23 studies as "1" and 12 studies as "0." The two raters' coding were identical for all 35 studies, except one study (#20), which Rater 1 and 2 coded as "0" and "1," respectively. The inter-rater reliability for Component 1 was very high (measurement of agreement kappa = 0.935, asymptotic standard error = 0.064, approximate T = 5.545, with approximate significance, $p < 0.001$). For Component 2, Rater 1 coded 26 studies as "1" and 9 studies as "0." The two raters' coding were identical for all 35 studies, except one study (#20), which Rater 1 and 2 coded as "0" and "1," respectively. The inter-rater reliability for Component 2 was very high (measurement of agreement kappa = 0.922, asymptotic standard error = 0.076, approximate T = 5.473, with approximate significance, $p < 0.001$). For Component 3, both Rater 1 and 2 coded 23 studies as "1" and 12 studies as "0." The two raters' coding were identical for all 35 studies. The inter-rater reliability for Component 3 was perfect (measurement of agreement kappa = 1.00, asymptotic standard error = 0.00, approximate T = 5.916, with approximate significance, p = 0.000). The inter-rater reliabilities for all Components were high, providing evidence for the reliability of coding of three Components for 35 studies. The two raters discussed the differences in coding and reached final agreements to use Rater 1's coding in the following analyses.

Associations between the coding of Tx effects on parenting stress index and components 1–3

The non-parametric correlations (Kendall's Tau-B and p-values) between the variables (the coding of intervention effects on PSI and Components 1–3) are summarized in Table 2. These results suggested that all three Components were significantly correlated with the intervention (Tx) effects on PSI total; Components 1 and 2 were highly correlated with each other; and Component 3 were not correlated with other Components, thus relatively distinct from either Component 1 or 2.

The associations between each of the three Components and the coding of the outcome variable were independently tested using the directional association test, Sommer's d. The results showed that each of the three Components can predict the Tx effect on PSI: For Component 1,

TABLE 1 The coding of studies included in the theory-guided quantitative analysis.

PMID	First author	Journal	Year	Target population	Sample size per group	Tx effect on PSI 1 = positive effect, 0 = otherwise	Component 1 1 = criteria met 0 = else	Component 2 1 = criteria met 0 = else	Component 3 1 = criteria met 0 = else
32817266	Medoff CB	Pediatrics	2020	Parents of infants who underwent surgery for congenital heart disease	Tx *n* = 71, Control *n* = 70	0	0	1	0
32432487	Cala Cala LF	Clin Pediatr (Phila)	2020	Low income new mothers	Tx *n* = 150, Control *n* = 150	1	1	0	1
32027150	Ross AM	J Fam Psychol	2020	Military families	Tx *n* = 53, Control *n* = 51	0	0	1	1
31808376	Whittemore R	Diabetes Educ	2020	Parents of youths w/Type 1 diabetes mellitus	Tx *n* = 81, Control *n* = 81	1	1	1	1
31583748	Poehlmann-Tynan J	Infant Ment Health J	2020	Parents of preschool children	Tx *n* = 25, Control *n* = 14	0	0	0	1
31342445	Rollins PR	J Autism Dev Disord	2019	Parents of children w/autism spectrum disorder	Tx *n* = 32, Control *n* = 24	1	1	1	1
31522896	Chen H	Patient Educ Couns	2020	Parents of children w/congenital cataract	Tx *n* = 93, Control *n* = 107	1	1	1	0
31107793	Knight RM	J Pediatr Gastroenterol Nutr	2019	Mothers of children w/behavioral feeding disorder	Tx *n* = 12, Control *n* = 12	1	1	1	1
31222789	McCarter DE	J Adv Nurs	2019	Mothers w/depression and anxiety symptom	Tx-I *n* = 181, Tx-II *n* = 189, Control *n* = 167	0	0	0	0
31165715	Sawyer A	J Med Internet Res	2019	New mothers w/depression and parenting problems	Tx *n* = 72, Control *n* = 61	0	1	0	0
31023190	O'Shea A	Psychiatr Serv	2019	Mothers w/schizophrenia spectrum or mood disorder	Tx *n* = 66, Control *n* = 65	1	1	1	1
30804992	Sgandurra G	Neural Plast	2019	Parents of low-risk preterm infants	Tx *n* = 24, Control *n* = 20	1	1	1	0
29855840	Lutenbacher M	Matern Child Health J	2018	Hispanic mothers of newborns	Tx *n* = 91, Control *n* = 83	1	1	1	0
29953626	Ericksen J	Infant Ment Health J	2018	Mothers w/a range of postnatal mental disorders, e.g., depression	Tx *n* = 16, Control *n* = 15	1	1	1	1
29921144	Luby JL	Am J Psychiatry	2018	Parents of children w/early developed depressive symptoms w/comorbidity of externalizing disorder.	Tx *n* = 115, Control *n* = 114	1	1	1	1
29413437	Kaltenbach K	Drug Alcohol Depend	2018	Mothers w/opioid use disorder	Tx *n* = 96 Pts in a within-subject design.	0	0	0	0
28929582	Hemdi A	Child Care Health Dev	2017	Mothers of chiildren w/autism spectrum disorder	Tx *n* = 34, Control *n* = 33	1	0	1	1
28881303	Lachman JM	Child Abuse Negl	2017	Parents of children at risk for maltreatment	Tx *n* = 34, Control *n* = 34	1	1	1	1
28830853	Boogerd E	J Med Internet Res	2017	Parents of child w/type 1 diabetes	Tx *n* = 54, Control *n* = 51	0	0	0	0

(Continued)

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TABLE 1 (Continued)

PMID	First author	Journal	Year	Target population	Sample size per group	Tx effect on PSI 1 = positive effect, 0 = otherwise	Component 1 1 = criteria met 0 = else	Component 2 1 = criteria met 0 = else	Component 3 1 = criteria met 0 = else
28739559	Sawyer MG	J Med Internet Res	2017	New mothers	Tx *n* = 491, Control *n* = 328	0	**0***	**0***	0
28647759	Rosenblum KL	Arch Womens Ment Health	2017	Mothers w/at least one of the following conditions: 1. a mother's history of childhood maltreatment, 2. adult interpersonal violence, 3. past or current depression and anxiety.	Tx *n* = 68, Control *n* = 54	1	1	1	1
28512921	Jones SH	J Child Psychol Psychiatry	2017	Parents w/bipolar disorder	Tx *n* = 47, Control *n* = 50	1	1	1	1
28464006	Koushede V	PLoS One	2017	Expectant mothers	Tx *n* = 863, Control *n* = 863	0	0	0	1
28410972	Luthar SS	Womens Health Issues	2017	Mothers w/work related burnout in medical settings	Tx *n* = 21, Control *n* = 19	1	1	1	1
27306883	Thijssen J	Child Psychiatry Hum Dev	2017	Parents of children w/ADHD	Tx *n* = 91, Control *n* = 55	1	1	1	1
27624608	Ehrensaft MK	J Prim Prev	2016	Mothers in college w/relatively high parental stress	Tx *n* = 26, Control *n* = 26	1	1	1	1
27878951	Hodes MW	J Appl Res Intellect Disabil	2017	Parents w/mild intellectual disabilities or borderline intellectual functioning	Tx *n* = 43, Control *n* = 42	1	1	1	1
27710006	DeVoe ER	Psychol Trauma	2017	Parents in military service about to be deployed	Tx *n* = 57, Control *n* = 58	1	1	1	1
27464071	Natrasony C	Phys Occup Ther Pediatr	2016	Mothers of children w/gross-motor delays	Tx *n* = 23, Control *n* = 16	0	0	1	0
27449367	Castel S	Early Hum Dev	2016	Parents of preterm infants	Tx *n* = 33, Control *n* = 32	1	1	1	1
26446726	Bagner DM	J Abnorm Child Psychol	2016	Mothers from underserved population	Tx *n* = 31, Control *n* = 29	0	1	1	0
27258925	Leung C	Res Dev Disabil	2016	Parents of preschool children w/developmental disabilities	Tx *n* = 62, Control *n* = 57	0	1	1	0
27302544	Ngai FW	J Psychosom Res	2016	Mothers w/postpartum depression	Tx *n* = 197, Control *n* = 200	1	0	0	1
26986919	Walton K	Can J Public Health	2016	Parents of preschool children	Tx *n* = 29, Control *n* = 25	1	0	1	1
26939716	Fonagy P	Infant Ment Health J	2016	Mothers at risk for mental health issues	Tx *n* = 38, Control *n* = 38	1	1	1	1

* Raters 1 and 2 differed in the coding.

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TABLE 2 The non-parametric correlations (Kendall's Tau-B and *p*-values) between the variables.

	Tx effect on PSI	Component 1	Component 2	Component 3
Tx Effect on PSI	1			
Component 1	0.620 **	1		
	$p < 0.001$			
Component 2	0.539 **	0.539 **	1	
	$p = 0.002$	$p = 0.002$		
Component 3	0.620 **	0.239	0.264	1
	$p < 0.001$	$p = 0.163$	$p = 0.124$	

** p-value < 0.005.

TABLE 3 The cross tabulations of the treatment effect on PSI and the coding of three components.

		Tx effect on PSI		
	Coding	Negative (Total # = 12)	Positive (Total # = 23)	Sum of row
Component 1	0	9	3	12
	1	3	20	23
Component 2	0	7	2	9
	1	5	21	26
Component 3	0	9	3	12
	1	3	20	23

TABLE 4 The cross tabulations of the treatment effect on PSI and the sum of coding.

	Tx effect on PSI			
Sum of coding	Negative effect (Total # = 12)	Positive effect (Total # = 23)	Total # each row	% Positive effect
0	4	0	4	0%
1	5	1	6	16.67%
2	3	6	9	66.67%
3	0	16	16	100%

the directional association, treating Component 1 as independent variable and the binary coding of Tx effects on PSI as dependent variable, was significant (Sommer's $d = 0.620$, standard error = 0.143, $T = 3.890$, $p < 0.001$). For Component 2, the directional association, treating Component 2 as independent variable and the Tx effects on PSI as dependent variable, was significant (Sommer's $d = 0.585$, standard error = 0.159, $T = 3.033$, $p = 0.002$). For Component 3, the directional association, treating Component 3 as independent variable and the Tx effects on PSI as dependent variable, was significant (Sommer's $d = 0.620$, standard error = 0.143, $T = 3.890$, $p < 0.001$). The cross tabulations of the outcome variable (Tx effect on PSI) and each of the Components are summarized in Table 3. The inclusion of each Component in a particular intervention was found to be associated with the reduction of parenting stress. This supports the importance of each Component in interventions for parenting stress.

Additionally, to test the additive effects of Components 1, 2, and 3 on the outcome variable (Tx effect on PSI), we computed the sum of coding for each study (which yields a possible total value of 0, 1, 2, or 3). The directional association, treating the sum of coding as independent variable and PSI as dependent variable, was significant (Sommer's $d = 0.591$, standard error = 0.064, $T = 7.698$, $p < 0.001$). The cross tabulations of the outcome variable (positive or negative Tx effect on PSI) and the sum of coding are summarized in Table 4 and Figure 4. The more Components the interventions had, the more likely parenting stress was attenuated in the reviewed studies. This supports the importance of including all three Components to maximize potential efficacy of the interventions for parenting stress.

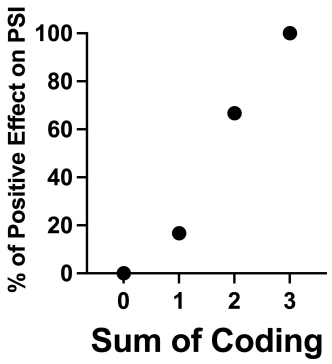

FIGURE 4
A monotonically increasing relation between the sum of coding of the studies included in the theory-guided quantitative analysis (on the *x*-axis) and the percentage of the included studies showing significant positive effects on reducing parenting stress (on the *y*-axis).

Relative contributions of three components to the Tx effects on parenting stress index

To explore relative contributions of three Components to the Tx effects on PSI, we examined the variance of the outcome variable (Tx effect on PSI) explained by the three Components, by performing logistic regression tests with different methods, namely enter, forward, and backward. In the enter model, all three Components were entered simultaneously as predictors, and they totally explained 79.8% of the total variance of the Tx effect on PSI, with 75% accuracy in predicting negative Tx effects (9 out of 12) and 95.7% accuracy predicting positive Tx effects (22 out of 23). In the forward model, Component 3 was selected to be the first single predictor that predicted the outcome the most, which explained 44.8% of the total variance, and subsequently Component 1 was added to the model, which additionally explained another 32.0% of the total variance, resulting in 76.8% of variance explained by Components 1 and 3. In the backward model, all three Components were initially included and subsequently Component 2 was removed from the model as its removal only reduced the total variance explained from 79.8 to 76.8%. Taken together, Components 1 and 3 were two relatively distinct predictors that explained 44.8 and 32% variances of the Tx effect on PSI, respectively, while Component 2 showed little added value in explaining the variance, which perhaps was due to its collinearity with Component 1. Together with correlation data presented in **Table 2**, these analyses based on logistic regression support the particular importance of Components 1 and 3 for developing effective parenting stress interventions in the future.

Summary of the theory-guided quantitative analysis

The theory-guided quantitative analysis of clinical studies of parenting interventions demonstrated the following points: (1) Evaluating parenting interventions on the basis of the three identified components motivated by the dyadic active inference model turned out to be useful and yielded consistent results in gaging the success or the failure of parenting interventions, and (2) the review's findings seem to suggest the importance of including three identified therapeutic components to be implemented in the development of parenting interventions.

Integrating our work with the literature on mother-infant dyadic interactions

To relate our work to the literature of developmental psychology succinctly, here we integrate the work that we presented above with the dyadic concepts that were identified in a systematic review of 82 unique studies on mother-infant dyadic processes, namely, Mutuality, Reciprocity, Attunement, Contingency, Coordination, Matching, Mirroring, Reparation, and Synchrony (Provenzi et al., 2018). While the authors of Provenzi et al. (2018) provided a theoretical description of the relationships among these dyadic concepts, they did not explicitly describe a formal model of a dyad in a strongly coupled state. We believe our work can complement the work of Provenzi et al. (2018), as discussed below.

In **Table 5**, Provenzi et al.'s theoretical definitions of the concepts of dyadic processes are listed in the second column; the relevance of these concepts to our dyadic model is described in the third column; the intervention components in our coding system that are likely to be involved in each of these dyadic concepts are listed in the fourth column.

The first two of the nine dyadic concepts identified in Provenzi et al. (2018) are Mutuality and Reciprocity, which are seen as overarching concepts underlying dyadic processes. In terms of our dyadic model, we consider Mutuality—mutual contribution of the interactive partners—as a concept to emphasize the strongly coupled state, as opposed to a weakly coupled state, between two persons. We consider Reciprocity—reciprocal influence between interactive partners—as a concept to emphasize the bi-directional cause and effect of the (A), (S), and (I) nodes of the dyadic active inference engine. Further, Provenzi et al. (2018) described two dynamic cycles emerging from their computer-aided text analysis, quoted in paragraphs below. **

> *"First, the ability to share intentions (i.e., attunement)—rather than simple behaviors or actions within the dyad—emerged as a more complex mutual engagement between the mother and the infant which is built upon low-level contingent engagement (i.e., contingency and coordination). From this perspective, mirroring should be considered as a specific way of being together, which might only appear*

> *when the mother is able to understand the behavioral and inner states of the infant in order to provide an exaggerated version of the observed and inferred infants' socio-emotional state. When effective mirroring occurs, greater levels of contingency might be reached by the dyad, so that mother and infant constitute a dynamic system characterized by a behavioral-psychological self-organized and homeostatic cycle"* (Provenzi et al., 2018).

Apparently, the above description of the first cycle—which involves attunement, contingency, coordination, and mirroring—is compatible with our description of the dyadic active inference engines that are strongly coupled—that is, by virtue of the coupling between the two engines' nodes (As) and (Ss) at the lower level, which result in the mirroring of the two agents, the attunement between the two engines' (I) nodes are achieved at the higher level.

> *"Second, a second cycle of matched and un-matched behavioral states within the dyad appeared to be regulated by dyadic reparation. Repeated matching emerged as the pre-condition for synchrony, which, in turn, contributed to heightened matching states. In other words, repeated in-moment matching states contribute to lagged moment-by-moment synchrony in time, so that reiterated interactive exchanges between mothers and infants grow in complexity in a reciprocal way"* (Provenzi et al., 2018).

Similarly, the above description of the second cycle—matching and the reparation of an unmatched state—is consistent with the process of perceptual and active inferences to update the prior beliefs such that the variational and expected free energy can be minimized eventually.

> *"In sum,. coordination (of behaviors) and attunement (of intentions) might be considered as two critical nodes which allow the mother-infant dyad to move from behavioral forms of involvement (i.e., contingency, matching) to more complex psychological and inner-state forms of dyadic engagement (i.e., attunement, synchrony)"* (Provenzi et al., 2018).

In sum, the above description of coordination at the behavioral level and attunement at the intentional level is consistent with the two levels of an active inference engine, the behavioral coupling between the dyad's nodes (As) and (Ss) in the lower level and the approximation of the dyad's prior beliefs in nodes (Is) in the higher level, respectively, (see **Figure 1**).

In the fourth column of **Table 5**, we list the dyadic concepts' relevance to the coding system of the interventions that we presented above. The intervention Components 1 and 2 aim to rehabilitate or promote the functioning that is largely relevant to the higher level, node (I), and lower level, nodes (A) and (S) of the active inference engines in a strongly coupled state, and both Components are similar to the concepts involved in the attunement of intentions and coordination of behaviors in Provenzi et al's terms, respectively. However, none of the dyadic concepts identified in Provenzi et al. (2018) would seem relevant to Component 3 (intervention to reduce over-mentalizing) in our coding system. This is because Component 3 is not within the scope of the work undertaken by Provenzi et al. (2018) and, rather, it is by and large a therapeutic inner work on one's awareness of self and other's inner thoughts, feelings, and intentions to rectify the problem of over-mentalizing. To dig deeper in this issue, in the following sections, we turn to Buddhist Philosophy of Mind (which is synonymous to awareness in the present context) to discuss the relational worldview that may help explain the root cause of invalid beliefs, its resulting excessive dyadic stress and unnecessary suffering, and the innate capacity of awareness to be free from invalid beliefs and suffering.

In short, by proposing the causal relationship among deficient relational benevolence due to invalid beliefs, under-coupling, and over-mentalizing that would result in excessive stress and impaired intersubjectivity, we believe that our work complemented Provenzi et al.'s comprehensive review work by addressing the following issues: (a) how dyadic interactions can influence maternal wellbeing, which is acknowledged by Provenzi et al. (2018) as lacking in the current literature, (b) how the dyadic active inference model and hence the quality of dyadic interactions can be compromised, and (c) how to most effectively intervene therapeutically to counteract with compromised intersubjectivity, which is corroborated in our theory-guided quantitative analysis of the literature on parenting interventions and parenting stress.

Understanding intersubjectivity and active inference in a relational worldview

While we have postulated that the hallmark of quality dyadic processes is intersubjectivity, how is intersubjectivity—the awareness of self and others—even possible in the first place? The answer depend on the "worldviews"—ontological and epistemological assumptions implicitly or explicitly used to understand any phenomena in this world—that are brought into the studies of awareness (mind) and/or metaphysics (mind-body relation; Avramides, 2020). While a worldview may not be easily falsifiable, not all worldviews garner scientific evidence equally. To make any science fruitful, the worldview that a scientific community adopts should be as consistent with the most fundamental nature of reality as possible. In this

section, we discuss how a relational worldview supported by Physics and Buddhist Philosophy can enrich our understanding of the nature of active inference, awareness, and intersubjectivity.

Toward an abstract expression of relational worldview according to physics and Buddhist Philosophy

As already described in the beginning, *living organisms are impermanently, inter-dependently self-organizing* through ceaseless interactions with their environments. It is emphasized in FEP that living organisms as active inference engines are self-evidencing in its environments by using their own actions to solicit their sensory inputs from the world. In a way, active inference is consistent with the notion of *participatory universe*—the outcome of measuring a quantum system depends on the apparatus chosen to perform the act of measuring—coined by John A. Wheeler, one of the greatest Physicists and Philosophers in our time.

Most physicists would agree that, ontologically, the universe is fundamentally relational, and, epistemologically, to be observable is to be interactable in physics (Rovelli, 2021). In the standard model of physics, fundamental particles are nothing but products of interactions of even more fundamental quantum fields (Peskin and Schroeder, 1995). The relational nature of the participatory universe has been rigorously demonstrated many times in a family of so-called *delayed-choice experiments*. This kind of experiments aims to demonstrate the dual nature of a quantum system, e.g., a single photon that can behave either like a particle or like a wave. In this kind of experiments, whether a single photon behaves particle-like or wave-like depends on whether a particle detector or wave detector is chosen to measure the photon's behavior. Because the act of choosing either one of the detectors to observe the single photon occurred after the very photon has completed its behavior, this kind of experiments are thus called "delayed-choice." After decades of rigorous delayed-choice experiments, most physicists would agree that:

> "*. . .no elementary phenomenon is a phenomenon until it is a registered phenomenon. . .some registered phenomena do not have a meaning unless they are put in relationship with other registered phenomena*" (Ma et al., 2016).

The notion of participatory universe suggests that all information is relationally dependent upon the existence of observations or observers whereas the existence of observations or observers is relationally dependent upon the ingredients of the universe. The observer here may be a living system, which is modeled as an active inference engine, or simply a quantum-system measuring apparatus that solicits and thus co-creates the outcomes of observing an incoming event.

To summarize the relational worldview underlying active inference and participatory universe, we resort to the notion of "Dependent Origination" that can be abstractly expressed in the following equation:

$$\text{Effect} = \text{Cause} \times \text{Condition} \quad (1)$$

Colloquially, Eq. 1 should read "Effect is an interactive product of Cause by Condition."

Both Cause and Condition are factors participating in an interaction that produces Effect. Among these factors, some are called "Cause," if they maintain certain *systemic continuity* with the "Effect"; others are called "Condition," if they lack apparent systemic continuity in relation to either Cause or Effect. The term *systemic continuity* is used here to refer to the relation between Cause and Effect—that they are continuous but successive phenotypes of the same system.

For example, fruit is an interactive product of its seed and other factors such as soil, bacteria, water, sunlight, farmer, etc. In this case, the fruit is Effect, the seed is Cause, and other factors are Conditions. There is systemic continuity between the seed (Cause) and fruit (Effect) because the seed and fruit belong to the same system defined by the same genes that they carry (systemic), but they never co-exist simultaneously in the temporal succession of seed and fruit (continuity). In contrast, while the other factors (soil, bacteria, water, sunlight, farmer, etc.) are necessary to produce the fruit, they are designated as Conditions because they lack the systemic continuity with either the seed or the fruit.

The interactive product, designated by the sign "×" in Eq. 1, renders Eq. 1 as a non-linear formula. Mathematically, the non-linearity mandates that Effect is neither a linear transformation of Cause, nor Condition, nor a linear combination thereof.

Interestingly, Eq. 1 can serve as a mathematical expression of the ultimate nature of reality, namely "Emptiness," that has been established by Arya Nagarjuna, the founder of Madhyamaka School of Buddhist Philosophy, in the following reasoning:

"Neither from itself,
Nor from another,
Nor from both,
Nor without a cause,
Does anything whatever, anywhere arise." (Nagarjuna, 1995) Ch. 1 V. 1

Arya Nagarjuna's reasoning on Emptiness can be translated in terms of Eq. 1, as follows:

"Neither from self" means that the Effect is not a linear transformation of its Cause—, e.g., although the fruit and seed carry the same genes, the fruit is not identical to the seed or a scaled-up version of the seed.

"Nor from other" means that the Effect is not a linear transformation of its Condition—, e.g., the fruit is not identical to soil, bacteria, water, sunlight, farmer, etc., that do not even share the same genes with the fruit.

"Nor from both" means that the Effect is not a linear combination of the Cause and Condition—, e.g., the fruit is not just the sum of the seed, soil, bacteria, water, sunlight, farmer, etc. that do not have any interactions among them.

"Nor without a cause" means that the Effect is not something other than an interactive product of Cause by Condition—, e.g., the fruit does not come to exist without being the effect of the interactions among the seed, soil, bacteria, water, and other conditions.

"Does anything whatever, anywhere arise" means that nothing can be observed without following the ultimate nature of the participatory universe.

In short, Eq. 1 is not only an abstract expression of "Dependent Origination," but also an axiomatic translation of Arya Nagarjuna's reasoning on "Emptiness." The resulting functional equivalence between "Emptiness" and "Dependent Origination" is eloquently reflected in the pith of Buddhist wisdom, as Je Tsongkhapa (1357–1419) stated in his masterpiece "In Praise of Dependent Origination" (Lobsang Gyatso and Woodhouse, 2011) that:

> *"When one sees Emptiness in terms of the meaning of dependent origination, then being devoid of intrinsic existence and possessing valid functions do not contradict."*
>
> —Je Tsongkhapa, translated by Geshe Thupten Jinpa.

The consistency between the Buddhist wisdom and John A. Wheeler's notion of participatory universe becomes evident when we summarize experimental evidence demonstrated in those delayed-choice experiments (Ma et al., 2016) as a special case of Eq. 1, that Effect of measuring a quantum system (e.g., a single photon) is an interactive product of Cause by Condition—wherein Cause is the to-be-measured single photon and Condition is the apparatus used to detect the photon's particle-like or wave-like behavior. When Conditions favor the single photon's wave-like or particle-like behavior, the photon will appear to behave like a wave or a particle, respectively, after it interacts with Conditions.

Altogether, the relational worldview in the current context specifically refers to the notion that Effect is as an interactive product of Cause by Condition, which can be equivalent to the notions of Dependent Origination and the ultimate nature of reality, Emptiness, in Buddhist Philosophy as well as the notion of Participatory Universe in Physics.

In the following sections, we will use similar abstract expressions to describe how intersubjectivity and active inference framework can be understood as additional special cases of this relational worldview.

Understanding intersubjectivity in the relational worldview

> *The acid test of every epistemology is, when all is said and done, the intersubjective relationship.*
>
> (Fuchs, 2017, p. 27)

Intersubjectivity—the awareness of self and other's intentions and feelings—is relational, because the effect of awareness in intersubjectivity depends on the interactive coupling between the participants. Here we apply the abstract expression of Dependent Origination to the nature of awareness and intersubjectivity.

According to the Buddhist science of mind, the nature of awareness is fundamentally relational, described as follows:

"The nature of cognition is stated to be awareness, and the nature of consciousness is said to be clear (or luminous) and aware. 'Clear' here expresses the essential nature of consciousness, and 'aware' expresses its function. 'Clear' also indicates: (1) that consciousness is beyond the nature of matter, which is characterized as tangible and obstructive, so it is clear in nature; (2) that just as reflections appear in a mirror, any internal or external object whatsoever—good or bad, pleasant or unpleasant—can appear in consciousness, so consciousness is luminous in that it illuminates objects; and (3) that the essential nature of consciousness is not contaminated by the stains of mental afflictions such as attachment, so its nature is clear or luminous." (Tenzin Gyatso, 2020, p. 41).

The relational nature of the awareness is often likened to a clear lampshade or mirror metaphorically, as discussed in our previous work (Ho et al., 2021). In the former, a clear lampshade is colorless (clear) and any object that the mind perceives is like a light bulb in the clear lampshade, which can color the lampshade with its light, e.g., the lampshade's color becomes blue when a light bulb emits blue light. However, just as the light bulb can never stain the lampshade, the object perceived by the mind can never stain the mind. Thus, the mind (lampshade) returns to its colorless clarity as soon as the object (light bulb) is turned off. In the latter, awareness is also likened to a mirror, as it reflects the object in front of the mirror, but the mirror is not the object nor the image in the mirror. In other words, the image in the mirror is an interactive product of the mirror and the object in front of the mirror.

Here we describe the mirror-like nature of the awareness in terms of the abstract expression of Dependent Origination.

TABLE 5 The relevance of present work to the literature of dyadic process as summarized in Provenzi et al. (2018).

Dyadic concepts	The concepts' definition provided in Provenzi et al. (2018)	The concepts' relevance to the dyadic active inference model in our work	The concepts' relevance to the coding system of interventions
Mutuality	Mutual contribution of the interactive partners, which might not be equal in terms of frequency and intensity of the behaviors of the two partners.	The necessity of using a dyadic model to describe and understand person-person interactions in a strongly coupled state.	Component 1 (promotion of symbiotic benevolence)
Reciprocity	Reciprocal influence between interactive partners.	The interaction at the level of nodes S and A between two partners at one moment will produce an effect on each person's internal model at the level of node M at the next moment after the interaction.	Component 1 (promotion of symbiotic benevolence)
Attunement	Sharing of actions and intentions which includes maternal identification of infant's inner feelings/states and infant's comprehension that the mother is referring to his own original state.	Attunement is very similar to intersubjectivity. As the internal modal (node M) of one partner is closely related to intentions that cause actions (node A) and feelings (node S) of the other partner subsequently causes internal model (node M), attunement is achieved when the mother's M of infant is consistent with the infant's M of his or her own nodes S and A.	Component 1 (promotion of symbiotic benevolence)
Contingency	Reciprocal adjustment of *trans*-modal affective and behavioral signals within a micro-temporal window that leads to infants' learning and regulation skills and interactive patterns.	Contingency reflects the operational working of an active inference engine in which one's internal model is optimized. The learning occurs after encountering surprisal and using perceptual inferences to minimize variational free energy. Skills are acquired after using active inference to minimize expected free energy.	Component 2 (intervention to reduce under-coupling)
Coordination	Bidirectional rhythmic exchanges characterized by specific timing and turn taking which facilitates the reciprocal prediction of future behavioral states.	Coordination is similar to the contingency in a strongly coupled state, wherein two persons take turn to observe, mirror, and respond to one another, creating rhythmic time-contingent dynamic relationships.	Components 2 (intervention to reduce under-coupling)
Matching	Simultaneous exhibition of the same affective and/or behavioral state by the mother and the infant.	Matching occurs in a strongly coupled state, wherein one person's node A causes the other's node S and *vice versa*. Because both persons' behavioral states (node A's) are similar, their affective states (nodes S's) are also similar. Matching is like simultaneous mirroring that may be more automatic or spontaneous than intentional mirroring, below.	Components 2 (intervention to reduce under-coupling)
Mirroring	Exaggerated/marked reflection of *trans*-modal child behaviors by the mother through imitation of affective quality reproduction in a temporally contingent way.	Mirroring is a special form of matching when matching may be more deliberately or intentionally performed than simultaneous matching. Mirroring can happen bidirectionally.	Components 2 (intervention to reduce under-coupling)
Reparation	Dyadic process in which unmatched dyadic states are transformed in matched dyadic states producing an opportunity to learn interactive strategies and to achieve better stress and emotion regulation.	Reparation is the minimization of dyadic stress by using the surprisal or prediction errors in a dyadic interaction to update the internal model(s) to minimize the surprisal in the next interaction. Because stress is proportional to the surprise, the reduction of surprise can reduce stress.	Components 1 (promotion of symbiotic benevolence) and 2 (intervention to reduce under-coupling)
Synchrony	Degree of congruence between *trans*-modal behaviors of two partners which is lagged in time and which promotes infants' learning of emotional regulation skills and the emergence of expectations on interactive repertoires.	Synchrony indexed by any observable indicators may reflect the degree of intersubjectivity as conceptualized in our dyadic model.	Components 1 (promotion of symbiotic benevolence) and 2 (intervention to reduce under-coupling)

For an object, A, let a subject's awareness of A be "A-ness," which is called the "qualia" of perceiving A. As Effect is an interactive product of Cause by Condition, "A-ness" is an interactive product of subject (Cause) and objects (Conditions), which include the object A and other environmental conditions, e.g., the subject's visual system and other physical environments. Note that the subject, not the object A, is designated as Cause because the qualia as Effect is a subjective experience that has the

systemic continuity with the subjectivity of the subject, whereas the object A does not have such systemic continuity. Therefore, in the realm of awareness, Eq. 1 can be re-expressed as follows:

$$\text{Effect}_{[\text{Qualia "A-ness"}]} = \text{Cause}_{[\text{Subject}]} \times \text{Condition}_{[\text{Object A}]} \quad (2a)$$

Using the mirror metaphor of the mind, the qualia "A-ness" is like the image in the mirror (Effect), the subject's mind is like the mirror (Cause), and the object A is like an object placed in front of a mirror (Condition).

In parallel, the object A should be changed after the subject-object interaction too. There should be a counterpart to $\text{Effect}_{[\text{Qualia}]}$, which can be re-expressed as follows:

$$\text{Effect}_{[\text{Object A}']} = \text{Cause}_{[\text{Object A}]} \times \text{Condition}_{[\text{Subject}]} \quad (2b)$$

wherein $\text{Effect}_{[\text{Object}A']}$ denotes the post-interaction object A, with the object A as its Cause and the subjects of awareness and environmental objects (e.g., the brain system and lights in the room) as its Conditions. Due to the subject x object interaction, such $\text{Effect}_{[\text{Object}A']}$ is effectively infusing the object with certain "mental energy" in a process called "cathexis." We will further discuss the concept of cathexis in the context of active inference framework below.

As the Ubuntu proverb says, "I am because you are," there is no independent subject "I" that can be designated without also simultaneously designating the objects of "other" in relation to the "I." The intersubjective awareness is a relational awareness of self and other. Trevarthen made a distinction between primary and secondary intersubjectivity (Trevarthen and Aitken, 2001). The former refers to "an infant's active and immediately responsive conscious appreciation of the adult's communicative intentions" and the latter refers to "the integration in the new form of cooperative person-person-object awareness" that combines object awareness (e.g., doing with things) and person awareness (e.g., communicating with persons).

The primary intersubjectivity is considered innate and mainly characterized by *embodied, affective, and intuitive forms of relationships*, preceding communications mediated by symbolic and verbal processes (Trevarthen and Aitken, 2001). A key attribute underlying primary intersubjectivity is spontaneous mimicry or voluntary imitation of others' facial expressions or manual gestures. Infants show spontaneous facial mimicry soon after birth (Meltzoff and Moore, 1977). When primary intersubjectivity is successfully executed and maintained, it leads to establishing the sense of safety and assurance that everything is all right at that moment.

Secondary intersubjectivity, which emerges around 9 months of age, incorporates objects into the mother–infant interactions, forming a person-person-object triadic relationship (Trevarthen and Hubley, 1978). Jointly attending to an object of shared interest is seen as a critical step toward a mutual incorporation of the other's perspective into shared experiences. The emergence of secondary intersubjectivity points to a major developmental milestone where shared joint activities between mother and infant can create a significantly more advanced level of interactive intersubjectivity that can support the development of higher cognitive capacity for language, reflection, and perspective-taking.

Here we focus on how to understand primary intersubjectivity in terms of the abstract expression of the relational worldview. Let Eqs 2a, 2b be applied to dyadic processes wherein two subjects, Person 1 (P1) and Person 2 (P2), are strongly coupled in their person-person interactions.

For Person 1,

$$\text{Effect}_{[\text{"P1}\times\text{P2-ness" in P1}]} = \text{Cause}_{[\text{P1}]} \times \text{Condition}_{[\text{P1} \times \text{P2}]} \quad (3a)$$

For Person 2,

$$\text{Effect}_{[\text{"P2}\times\text{P1-ness" in P2}]} = \text{Cause}_{[\text{P2}]} \times \text{Condition}_{[\text{P2}\times\text{P1}]} \quad (3b)$$

The notations, Effects, on the left side of the equations are: $\text{Effect}_{[\text{"P1}\times\text{P2-ness" in P1}]}$ denotes P1's qualia about P1 × P2 dyadic interactions, i.e., "P1 × P2-ness," and $\text{Effect}_{[\text{"P2} \times \text{P1-ness" in P2}]}$ denotes P2's qualia about P2 × P1 dyadic interactions, i.e., "P2 × P1-ness." The notations on the right side of the equations are: $\text{Cause}_{[P1]}$ or $\text{Cause}_{[P2]}$ denotes P1 or P2's mirror-like awareness as the subjects; $\text{Condition}_{[P1 \times P2]}$ or $\text{Condition}_{[P2 \times P1]}$ refers to the conditions that interact with the mirror-like awareness, which can be any objects or behaviors of the dyadic system, e.g., the dyad's brains, bodies, verbal or physical behaviors, during the dyadic interactions.

As mentioned above, the Buddhist notion of mirror-like awareness suggests that "the essential nature of consciousness is not contaminated by the stains of mental afflictions such as attachment, so its nature is clear or luminous." (Tenzin Gyatso, 2020, p. 41). Eqs 3a, 3b do not guarantee that all qualia of "P1 × P2-ness," or "P2 × P1-ness," are equal in its level of intersubjectivity. Instead, the capacity of P1 or P2's intersubjectivity ($\text{Effect}_{[\text{"P1} \times \text{P2-ness" in P1}]}$ or $\text{Effect}_{[\text{"P2} \times \text{P1-ness" in P2}]}$) depends on the quality of the conditions ($\text{Condition}_{[P1 \times P2]}$ or $\text{Condition}_{[P2 \times P1]}$) that one's mirror-like awareness ($\text{Cause}_{[P1]}$ or $\text{Cause}_{[P2]}$) interacts with. In other words, Eqs 3a, 3b can be applied to any level of intersubjectivity, whether it is an optimal level of intersubjectivity (as depicted in **Figure 2**) or a sub-optimal level of impaired intersubjectivity (as depicted in **Figure 3**).

Understanding active inference framework in the relational worldview

The relational worldview—Effect is an interactive product of Cause by Condition—can be applied to understand the active inference framework. In the active inference framework, actions in active inference co-create the perceptions with the incoming

event, which is analogous to the facts that actions of measuring co-create the effects of the measurement of the quantum systems in delayed-choice experiments in Physics. When a person or agent is modeled as an active inference engine, the engine serves as the subject that interacts with an object in the external world. As an example, here we apply the abstract expression of Dependent Origination to the active inference process in the four-node network (**Figure 1**).

Let nodes (A), (S), and (I) of an active inference engine be the Cause and node (E) in the external state be objects or events be the Condition that interacts with the Cause in Eq. 1. Now we have a pair of expressions as follows:

For the effect on the active inference engine,

$$\text{Effect}_{[\text{nodes (A')}, \text{(S')}, \text{(I')}]} = \text{Cause}_{[\text{nodes (A)}, \text{(S)}, \text{(I)}]} \times \text{Condition}_{[\text{node (E)}]} \quad (4a)$$

wherein $\text{Effect}_{[\text{nodes(A')},\text{(S')},\text{(I')}]}$ designates the active inference engine *after* the Cause by Condition interaction, which involves iterations of perceptual and active inferences to optimize the prior beliefs to minimize the variational free energy in FEP. The systemic continuity between the Cause and Effect in Eq 4a is consistent with the notion that active inference engines are self-evidencing (Friston, 2018; Friston et al., 2022).

For the effect on the external state,

$$\text{Effect}_{[\text{node (E')}]} = \text{Cause}_{[\text{node (E)}]} \times \text{Condition}_{[\text{nodes (A)}, \text{(S)}, \text{(I)}]} \quad (4b)$$

wherein $\text{Effect}_{[\text{node (E')}]}$ designates the external state after the Cause by Condition interaction. Notably, the subject-by-object interaction effect on the object is denotated as the "cathexis" here, because it potentially entangles the object with certain orientation or propensity of the subject. For example, Edward Tolmen construed the process of cathexis as the learned tendency to associate certain objects with certain drives, which is one of the major determinants of choice behaviors, e.g., why meat lovers tend to satisfy their hunger with meat (positive cathexis) rather than non-meat products (negative cathexis; Tolman, 1945).

In the neuroscience literature, the cathexis effect is usually conceptualized in terms of the construct of incentive value—a positive or negative cathexis of an object is construed as a positive or negative incentive value of the object, respectively, (Dickinson and Balleine, 1994; Balleine and Dickinson, 1998). For example, a rat has tasted a very salty liquid solution and then does not consume the same solution anymore. In this case, the very salty solution has a negative incentive value for the rat.

The question is, after the negative incentive value of the solution has been established, what would the rat do when it is put in a salt-deprived state and then encounters the same salty solution again? This is the question ingeniously answered in an animal study, which showed that when the rat re-encountered the very salty solution after being put in a salt-deprived state surgically, it immediately ran toward and consumed the very salty solution appetitively (Robinson and Berridge, 2013).

As explained above, the non-linearity in those abstract expressions of Dependent Origination, including Eq. 4b, mandates the following three rules mathematically: The effect of Cause-by-Condition interaction, node (E'), is not identical to (1) any linear transformation of node (E), (2) nor a linear transformation of nodes (A), (S), (I), and (3) nor a linear combination of all four nodes. Hence, the incentive value of an object, *post-cathexis,* is not a property of the object, nor an internal representation encoded in the subject, nor a linear combination of the external object and internal representation.

The above axiomatic reasoning based on the non-linearity of Eq. 4b is corroborated by the experiments conducted by Robinson and Berridge (2013). As their study demonstrated an instant flip of the incentive value of the salty solution, from something negative to something positive, without any new learning, it is strongly suggested the following: The incentive value is not a property of the object, because the salty solution is not manipulated at all in their study. Nor the incentive value is encoded as the subject's internal representation. The reason for this refutation is that, had this notion been true, the rat would have avoided the salty solution even when it was salt-deprived after surgery, because (a) presumably the internal representation of the salty solution in the brain was not altered by the experimental manipulations and (b) the rat did not have any new learning trials to encode a new internal representation of the solution's incentive value in the novel salt-deprived state, as a representationalist account of the cathexis of incentive value would predict (Balleine and Dickinson, 1998).

This experimental refutation of the representationalist account of the cathexis of incentive value is potentially relevant to the refutation of the representationalist account of active inference, as noted in the FEP literature (Ramstead et al., 2020). The refutation of the representationalist accounts in the domains of incentive value and active inference speaks to the incompatibility between the relational worldview and realist worldview, to be further discussed below.

The incompatibility between the relational worldview and realist worldview

As we abstractly denoted the relational worldview as the notion of Dependent Origination—Effect is an interactive product of Cause and Condition, a realist worldview presents a stark contrast. Realism can be defined as follows:

> *"In general, where the distinctive objects of a subject-matter are a, b, c, and so on, and the distinctive properties are F-ness, G-ness, H-ness and so on, realism about that subject matter will typically take the form of a claim like the following:*

> *a, b, and c and so on exist, and the fact that they exist and have properties such as F-ness, G-ness, and H-ness is (apart from mundane empirical dependencies of the sort sometimes encountered in everyday life) independent of anyone's beliefs, linguistic practices, conceptual schemes, and so on."* (Miller, 2021)

In other words, the realism assumes a non-participatory universe wherein an object's ultimate *real* ontology (*a, b, c and so on*) is *identical* to its properties (*F-ness, G-ness, H-ness and so on*) that can be observed and ascertained, independent of the subject/observer/apparatus involved in the observation. In an abstract expression, a realist worldview can be expressed as follows:

$$\text{Existence}_{[a,\ b,\ c \text{ and so on}]} = \text{Observable}_{[F\text{—ness},\ G\text{—ness},\ H\text{—ness and so on}]} \quad (5)$$

The incompatibility between the realist and relational worldviews is clearly evident in preceding discussions offered here. First, in contrast to the non-linearity in the abstract expression of relational worldview (Eqs 1–4), Eq. 5 is a linear function. Second, in contrast to Eqs 1–4, the subject or the apparatus used to make observation plays no roles at all in Eq. 5.

This incompatibility may point to the innate possibility of the cessation of suffering, i.e., healing. We postulated in Ho et al. (2021) that an invalid belief—the belief that self or other is fixed and unchanged after any person-to-person interactions—is the root cause of entrapping one's awareness in an unhealthy state characterized by rigidity and inflexibility. The consequence of invalid beliefs in one's awareness is that one will misattribute the cause of his or her subjective experiences (qualia) to the object itself, rather than the interactive product of his or her active inference engine by the object. In this misattribution, one judges the value of the object based on one's own qualia ("this object makes me feel good/bad"), which one misbelieves to be identical to the object's ultimate existence ("this object is good/bad in and of itself"), such that one would believe that he or she can only have or not have the object, rather than participate both in the creation of the qualia and in the unfolding of how the object appears to be in accordance with the ultimate nature of the reality, Dependent Origination.

In fact, invalid beliefs are deeply embedded in the realist worldview or beliefs. In Buddhism, such realist beliefs are called conceptual thoughts (*Vikalpas*), and the substantial bases underlying these realist beliefs are called mental fabrication or superimposition (*Prapañca*). In the root text of Madhyamaka Philosophy, Arya Nagarjuna provided the diagnosis and treatment for cyclic suffering caused by *Vikalpa and Prapañca*, stating:

> "Action and misery having ceased, there is nirvana.
> Action and misery come from conceptual thought.
> This comes from mental fabrication.
> Fabrication ceases through emptiness." (Nagarjuna, 1995) Ch. 18, V. 5

We have discussed the types of conceptual thoughts and levels of mental fabrication, as well as how these processes adversely influence the active inference processes of the brain in thinking about compassion elsewhere (Ho et al., 2021).

According to Buddhism, suffering is rooted in invalid beliefs and the cessation of suffering is guaranteed because all views laden with invalid beliefs are incompatible with the ultimate nature of reality (Tenzin Gyatso, 1997, 2009). Arya Nagarjuna's prescription of cessation of suffering, as quoted above, can be paraphrased as follows: since the ultimate nature of reality—whether it is called Emptiness, Dependent Origination, or Participatory Universe in the context of the relational worldview—is incompatible with the realist worldview that can result in suffering, the cessation of suffering is always possible through the realization of the ultimate nature of reality by living in this participatory universe in the absence of invalid beliefs in one's awareness and active inference engines.

Among the initial steps toward this goal, what we hoped to clarify through the abstract expressions presented above is the critical importance of cultivation of an inward, reflective contemplation, including being aware of one's own prior beliefs in his or her internal states, the difference between the relational and realist worldviews underlying his or her prior beliefs, and the incompatibility between the realist worldview and the relational worldview concerning the nature of reality. Promoting such awareness is primarily an educational, contemplative work on changing beliefs and behaviors that are thought to hinder healthy dyadic interactions. By applying the abstract expressions and formal dyadic model to the study of the parenting interventions as an example domain, we indeed found that the cultivation of inward contemplation (i.e., Component 3 in the coding system) played a critical role in the efficacy of parenting interventions for reducing stress.

Conclusion

> *There is nothing more practical than a good theory.*
>
> —Lewin (1952, p. 169)

> *There is nothing as effective as the interdependence between theory, research, and practice.*
>
> —David Bargal (Bargal, 2012)

In this hypothesis and theory paper, our work is presented with *interdependence* among the aspects of theory, research, and practice related to intersubjectivity. To recapitulate, these interdependent aspects include (1) intersubjectivity as a hallmark of quality dyadic processes; (2) a framework of active inference engine in weakly coupled and strongly coupled states; (3) how intersubjectivity can be impaired by deficient relational benevolence due to invalid beliefs, under-coupling, and over-mentalizing; (4) a theory-driven literature analysis to evaluate our hypotheses designed to determine the extent to which parenting interventions were effective in reducing parenting stress on the basis of our dyadic model; (5) how our work can be integrated with the literature of developmental dyadic processes; and (6) a series of abstract expressions/notations to elucidate the relational worldview as supported in multiple scientific domains, how the relational worldview differs from the realist worldview, and the importance of the awareness of such distinction in relieving oneself from suffering according to Madhyamaka Philosophy.

First, we used a well-established framework, namely Free-Energy Principle, to provisionally construe a dyadic active inference model of intersubjectivity. Specifically, two persons, as active inference engines, are strongly coupled when one person's action causes the other's feeling and *vice versa*. In a strongly coupled dyadic system, variational free energy will be collectively minimized in a state of high-level intersubjectivity. The literature has suggested that stress can be defined as excessive variational free energy that threatens a person's self-centered beliefs. Thus, the dyadic active inference model predicts that a high level of intersubjectivity in a strongly coupled dyad will lead to minimize variational free energy and stress, while a low level of intersubjectivity in an under-coupled dyad will lead to engender excessive variational free energy and stress. Using child and mother as a focal example of person-to-person interactions in our investigation of intersubjectivity, our provisional work has led to identify three inter-related components to predict the compromised levels of intersubjectivity and increased stress, and we suggested three relational components and underlying brain networks that can serve as potential treatment targets for parenting interventions to reduce parenting stress.

Second, the results from quantitative evaluation of reviewed studies suggest that (1) the presence of any one of the three components was associated with success of parenting stress interventions and (2) the more components were included in an intervention, the more likely it was effective in reducing parenting stress. Pragmatically speaking, future intervention programs designed to attenuate parenting stress, regardless of any specific clinical therapeutic orientation, should consider the implementation of the three components to reduce parenting stress by enhancing the level of intersubjectivity in parent-child dyads.

Third, we integrated our work with decades of research in developmental psychology by comparing our work with the dyadic concepts identified in a recent systematic comprehensive review of dyadic processes (Provenzi et al., 2018). The compatibility between our dyadic model and the conceptual framework provided in Provenzi et al. (2018), along with the success in the theory-driven literature analysis in clinical studies, strongly supported the usefulness of our dyadic model in advancing the study of dyadic interactive process for future clinical application.

Fourth, using abstract expressions of Dependent Origination—Effect is an interactive product of Cause by Condition—in multiple domains, we explored the normality, impairment, and rehabilitation of intersubjectivity through the lens of the relational worldview.

In short, we presented an overarching framework grounded in the relational worldview for understanding the nature of reality. Articulating the relational worldview as effectively as possible may be the key to unlock the Team Human's potentials to overcome human-made problems. While we desperately need to rebuild a viable Team Human to respond to multiple planetary challenges (wars, violence, climate change, poverty, erosion of trust, collapse of democracy, etc.), we suggest that the rehabilitation of intersubjectivity should take a center stage in our collective effort to mitigate harms that are caused by humans.

Data availability statement

The original contributions presented in this study are included in the article/supplementary material; further inquiries can be directed to the corresponding author.

Author contributions

SH is the principal developer of the theoretical framework and hypotheses and writer of the manuscript, he created the figures in the study. YN has collaborated with SH in developing and refining the theoretical framework, he also co-wrote the manuscript. MG contributed to quantitative analysis of parenting intervention studies, especially in reviewing and coding of those studies. JS co-wrote the manuscript and supported the research involved in the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Skin-to-skin SDF positioning: The key to intersubjective intimacy between mother and very preterm newborn—A pilot matched-pair case-control study

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Background: Skin-to-skin contact (SSC) has been widely studied in NICU and several meta-analyses have looked at its benefits, for both the baby and the parent. However, very few studies have investigated SSC' benefits for communication, in particular in the very-preterm newborn immediately after birth.

Aims: To investigate the immediate benefits of Supported Diagonal Flexion (SDF) positioning during SSC on the quality of mother—very-preterm newborn communication and to examine the coordination of the timing of communicative behaviors, just a few days after birth.

Subjects and study design: Monocentric prospective matched-pair case-control study. Thirty-four mothers and their very preterm infants (27 to 31+6weeks GA, mean age at birth: 30weeks GA) were assigned to one of the two SSC positioning, either the Vertical Control positioning (n=17) or the SDF Intervention positioning (n=17). Mother and newborn were filmed during the first 5min of their first SSC.

Outcome measures: Infants' states of consciousness according to the Assessment of Preterm Infants' Behavior scale (APIB). Onset and duration of newborns' and mothers' vocalizations and their temporal proximity within a 1-s time-window.

Results: In comparison with the Vertical group, very preterm newborns in the SDF Intervention Group spent less time in a drowsy state and more in deep sleep. At 3.5days of life, newborns' vocal production in SSC did not differ significantly between the two groups. Mothers offered a denser vocal envelope in the SDF group than in the Vertical group and their vocalizations were on average significantly longer. Moreover, in a one-second time-frame, temporal proximity of mother-very preterm newborn behaviors was greater in the SDF Intervention Group.

Conclusion: Although conducted on a limited number of dyads, our study shows that SDF positioning fosters mother-very preterm newborn intimate encounter during the very first skin to skin contact after delivery. Our pioneer data sheds light on the way a mother and her very preterm vocally meet, and constitutes a pilot step in the exploration of innate intersubjectivity in the context of very preterm birth.

KEYWORDS

first skin-to-skin contact, SDF positioning, mother-very preterm newborn interaction, innate intersubjectivity, Kangaroo Care, NICU, vocal production, very premature birth

Introduction

In the 1970s, scientists brought evidence that, before they actually begin to speak, newborns, as well as young infants, experience intersubjective awareness. Their thoughts develop through the sympathetic and timely engagement with the expressive behaviors of a sensitive parent (Bruner, 1977; Trevarthen, 1977; Bateson, 1979; Brazelton, 1979; Brazelton et al., 1979). The centrality of interpersonal synchrony was highlighted through pioneer studies using videotape recordings of mother–infant interactions (Trevarthen, 1977; Tronick et al., 1977; Feldman et al., 1999; Jaffe et al., 2001). The present study falls within the psychobiological theory of intersubjectivity (Trevarthen, 2012, 2016). The theory of innate intersubjectivity claims that "a child is born with motives to find and use the motives of other persons in 'conversational' negotiation of purposes, emotions, experiences, and meaning. The efficiency of sympathetic engagement between persons signals the ability of each to 'model' or 'mirror' the motivations and purposes of companions, immediately" [Trevarthen, 1998 (in Braten) p. 16]. In this perspective, achieving a conversation at birth rests on an efficient mobilization of the neonate's internal resources (self-regulation), as well as on the efficient sympathetic regulation of a partner. The theory of innate intersubjectivity considers newborn and partner as an intrinsic unit, the dyad. It is especially activated during intimate dyadic free play. In such face-to-face, eye-to-eye intersubjective emotional communications, infant and mother intently look at and listen to each other. Thereby, they synchronize and regulate each other's emotional states. During these protoconversations, the partners' emotions are expressed and actively perceived in spontaneous, reciprocal, and rhythmic-turn-taking interactions (Trevarthen, 1993). In this perspective, the dyad becomes the place where they meet, as well as where they miss each other. Every time they meet or miss each other results from an intelligent combination of their ability to perceive each other's motives. In her tribute to Stern, Beebe (2017, p. 234) stated that "the meaning of the behavior is co-created," recalling that the way communication is bidirectionally regulated is specific to a particular dyad. Feldman et al. (2011) developed a similar neurophysiological model, including physiological synchrony from birth: when mother and child are physically close, they synchronize their breathing and heart rate. This provides a basis for later "social synchrony," in which partners meet and miss one another and respond during shared interactions. But sometimes birth comes earlier than expected and requires hospitalization, thereby separating mother and child and medicalizing their first relations. The present study investigates the essential question of how and to what extent the quality of communication can be supported from the start in the context of very preterm birth.

Abbreviations: APIB, Assessment of preterm infants' behavior scale; IFCDC, Infant- and Family-Centered Developmental Care; GA, Gestational age; NICU, Neonatal intensive care unit; SDF, Supported diagonal flexion; SSC, Skin-to-skin contact.

Before term birth

For the fetus, pregnancy is a time for chemosensory learning, which helps him adapt to his new after-birth environment (Lickliter, 2000). The uterine environment provides plentiful multisensory stimulations. The fetus can experience vestibular, somaesthetic, auditory, chemical and olfactory stimulations, simultaneously or sequentially (Pinéda et al., 2017a).

In utero, the fetus moves intentionally, with controlled timing and sequencing, anticipating sensory confirmation of self-related effects (Piontelli, 2010). The fetus is bathed in an environment of vestibular, somatosensory, tactile, and auditory rhythmic stimuli, through the mother's breathing, heartbeats, walking, dancing, running, speaking, singing, etc. (Provasi et al., 2021). After 20 weeks, some fetuses make self-touching gestures with their left hand, which may signal sympathetic emotional attitudes with a mother's feelings of stress, and respond positively to her voice (Reissland and Kisilevsky, 2015). Various sounds are present in the uterus, with frequencies and intensities that are low yet detectable by the fetus (Philbin, 2017). When the mother speaks or sings, sound travels through the inside but also through the air, enabling

the fetus to perceive her voice from both internal and external sources (Pino, 2016). Fetuses are able to clearly identify the mother's voice, and could shape mouth movements when they hear someone speaking (Marx and Nagy, 2015). Toward the end of pregnancy, fetuses are particularly attuned to maternal acoustic cues (Ferrari et al., 2016) and they are able to detect, recognize, respond, and remember some characteristics of her voice (Kisilevsky et al., 2003; Voegtline et al., 2013).

Term birth

Babies are equipped to perceive the world they are born into. Newborns have a holistic perception of others: they perceive faces, voices, body movements, tactile stimuli, smells, and shapes. Evidence suggests that the mother's voice is one of the major drivers of the intricate intersensory and intermodal connections that are formed and retained in memory in the days following birth (Gratier and Devouche, 2017). The mother's voice is a salient, consistent and frequent stimulus that provides before-after birth continuity, regardless of the drastic changes linked to the exit of the uterine environment (Lickliter, 2000). From that perspective, the full-term newborn experiences a normal biological continuum between intra- and extra-uterine lives. At birth, the newborn is exposed to multimodal stimulations that form intermodal redundancies (joint and repeated apprehension of the environment with different sensory modalities; Provasi et al., 2014). This gives meaning to the newborn's environment, making his/her ecological niche. Significant biological stimulations originating from the mother, notably on the olfactory (Varendi et al., 1997) and auditory levels (Doheny et al., 2012), lead to an improvement of physiological and behavioral stability and better adapted responses.

A parent, or any caring elder, can pick up on the infant's skills to regulate him- or herself as well as the partner, thus enabling the development of a new and unique relationship of intimate familiarity and responsiveness (Brazelton et al., 1979; Trevarthen, 2011; Devouche and Gratier, 2019). In this context, Dominguez et al. (2016) and Boiteau et al. (2021) highlighted a tight coordination in the timing of vocalization between 2 to 4-day-old neonates and their parent. In both studies, neonates demonstrated control over the timing of vocalizations produced with an attentive and affectionate partner, with a 1-s temporal window explaining most baby-parent vocal contingencies. However, to date, no study has explored temporal coordination between the newborn and a partner in the context of preterm birth.

Preterm birth

Preterms have been denied part of their prenatal chemosensory learning time, and deprived of the typical biological continuum between pre- and postnatal life. In addition, after birth, they have to face the incubator's harsh environment that combines sensory deprivations, over-stimulations and inappropriate stimulations (Lickliter, 2000), which do not match their pre-organized sensory expectations. Preterm babies receive many sensory stimulations that are not adapted to their sensory maturation level, including more and higher levels of auditory stimulations (machine noises and rings, voices that are transformed and amplified by the incubator's walls) and reduced vestibular stimulation, at a time when they should be benefiting from filtered auditory stimulations, and regular vestibular stimulations provided by the mother's movements (Lickliter, 2000). They are also likely to be subjected to visual over-stimulations (bright lights) sometimes necessary in highly technical care. Furthermore, they are confronted to many unpleasant (antiseptic agents) but very few familiar or maternal smells (Marlier and Schaal, 2005). The preterm newborn is thus exposed to early sensory experiences that are atypical, both in quality and quantity, and that occur during the most critical period for the nervous system's development (Pinéda et al., 2017b; Montagna and Nosarti, 2016).

At birth, preterms' motor and interactional skills are fragile, which makes it is more difficult for them than for healthy term babies, to initiate an exchange and respond actively (Muller-Nix et al., 2004). However, they can discriminate between two stimuli, associate events, and become habituated to external stimulations. The preterm infant does receive environmental input and plays an active part in the interactive system (Provasi, 2019). Nevertheless, interactions between mothers and preterm children often involve poorer maternal adaptation to the infant's signals, leading to less maternal touch, as well as fewer vocalizations and gazes (Feldman, 2006; Forcada-Guex et al., 2011).

Preterm birth is associated with high stress and anxiety levels in parents (Segre et al., 2014), including post-traumatic stress (Forcada-Guex et al., 2011; Anderson and Cacola, 2017). A correlation has been evidenced between maternal and paternal stress, as well as between parental stress and the quality of father–mother–infant interactions in premature (Gatta et al., 2017). In the meta-analysis of Grote et al. (2010), 39% of mothers with a preterm baby presented postpartum depressive (PPD) symptoms. De Paula Eduardo et al.'s (2019) systematic review analyses the studies that explored preterm birth as a risk factor for postpartum depression in the last 10 years, and provides evidence of higher risk for PPD among mothers of preterm infants up to 24 weeks after childbirth. Stressful or traumatizing events have been shown to slow down oxytocin release, which inhibits the mother's empathetic abilities (Feldman, 2015). Indeed, mothers of preterm infants provide a less responsive and stimulating environment than mothers of full-term infants (Muller-Nix et al., 2004). Preterm birth could permanently disturb the interactional sphere (Zelkowitz et al., 2009). The analysis of preterms' neurological and behavioral disturbances highlights the entanglement between biological vulnerability (brain alteration) and environmental factors, such as stress, perinatal pain, and break of the emotional connexion with the mother (Montagna and Nosarti, 2016).

Pierrat et al. (2021, the EPIPAGE 2 study) showed that at age 5, behavioral disturbances were parents' most frequent preoccupation in France. This study also showed that the level of prematurity is crucial to neurodevelopment: moderate or severe developmental difficulties observed in 27% of extreme preterm children, 19% of very preterm children, and 12% of moderately preterm children. Irrespective of the degree of prematurity, 35% of preterms require adapted care to prevent difficulties from impacting the child's daily life and learning. More precisely: 50% of extreme preterms, 1/3 of very preterm children and ¼ of moderately preterm children received support in their development (speech therapy, psychomotor education, psychological support …). In the OLIMPE study, an ancillary study to EPIPAGE 2, Cambonie et al. (2017) recorded disorganized interactive behaviors on discharge from the maternity ward (50% for mothers, 33% for preterm babies), which persisted at 6 months (32% for mothers and 26% for preterms).

Skin-to-skin contact

Skin-to-skin contact is a consistent and reciprocal interaction, which is entirely dedicated to the parent-infant relationship. It is performed routinely around the world, starting from birth, as part of intensive care in neonatal units (Nyqvist et al., 2010). Skin-to-skin contact is offered during hospitalization, as part of family-centered care programs, as a support of the subjective experience of parenthood (Roué et al., 2017). This natural relational opportunity helps parents develop a sense of responsibility that is often on hold while the infant is in medical care. Skin-to-skin contact, along with infant-directed singing, allows mother and child to synchronize rhythmically and provides an envelope that enables the tuning of different rhythmic stimulations (Markova et al., 2019). Supporting mutual synchrony through SCC is in line with Thomson et al.'s (2013) recommendation to include some sense of coherence into the neonatal environment, by giving parents a central role in the decision-making process and supporting their engagement to care for their child.

In the specific context of a preterm birth, SSC has immediate physiological and neurobehavioral benefits (Feldman and Eidelman, 2003): it facilitates the vulnerable newborn's adaptation to extra-uterine life (Kristoffersen et al., 2016). Longer-term benefits include better psychomotor (Feldman et al., 2002) and cognitive development (Charpak et al., 2005; Feldman et al., 2014). Mothers and fathers of preterm newborns experience an increase of oxytocin release and a reduction in cortisol and stress responses during SSC, as well as facilitated breastfeeding (Cong et al., 2015; Mörelius et al., 2015). Mothers' psychological benefits include reduced stress and postpartum depression risk (Athanasopoulou and Fox, 2014; Zhao and Zhang, 2020). Additional benefits have been evidenced on parents' affective and interactive behavior at corrected term, as well as on the quality of their attachment (Tallandini and Scalembra, 2006; Moore et al., 2016; Feldman et al., 2014). Furthermore, SSC may promote parental presence, even in poor reception conditions (Raiskila et al., 2017).

Indeed, SSC has been widely studied (Charpak et al., 2005) and several meta-analyses or meta-syntheses have investigated its implementation (Seidman et al., 2015; Chan et al., 2016) or its benefits (Moore et al., 2016; Lawn et al., 2010; Mori et al., 2010; Anderzen-Carlsson et al., 2014; Johnston et al., 2017; Conde-Agudelo et al., 2011).

There has been a real paradigm shift toward family-centered care (Franck and O'Brien, 2019; Skene et al., 2019). In their paper presenting eight principles for patient-centered and family-centered care for newborns in the Neonatal Intensive Care Unit (NICU), Roué et al. (2017) listed the main benefits of SSC, however omitting to mention potential benefits for communication. Studies investigating this aspect are scarce. In their systematic review on the effects of early communication intervention on the speech and communication skills of preterm infants in the NICU, Harding et al. (2019) identified five studies, all conducted on very or extremely preterm babies, with outcome measures collected 1 month after birth (one study) and at 3 months CA or more (four other studies). Importantly, four of these studies correlated infant and mother measures but none actually focused on communication during SSC. Only Caskey et al. (2014) investigated the timing and coordination of parent-preemie communications, through a turn-taking measure computed by the LENA system, with a 5-s time window of temporal contingency. Authors considered any block that contains both infant and adult speech as conversational and found that infants responded preferentially and more frequently to their mothers compared with their fathers. However, their measure of coordination timing remained less precise than the one used by Dominguez et al. (2016) and Boiteau et al. (2021).

The search terms used for the Harding et al. (2019) review excluded several studies, such as Tallandini and Scalembra (2006), Feldman et al. (2014), or Buil et al. (2016) that nonetheless focused on mother-preemie communication. The study conducted by Buil et al. (2020) precisely aimed to investigate how communication could be improved during SSC, by modifying SSC positioning. Considering that mothers often complained about the impossibility to look at their baby's face, because of the vertical positioning of their child on their chest (leading them to sometimes prefer an arm-holding cuddle), authors investigated how an innovative kangaroo Supported Diagonal Flexion (SDF) positioning influenced mother and infant well-being and communication during SSC, while maintaining a safe and preventive preterm posture (Buil et al., 2016). This positioning was developed in a high-tech NICU according to recent experts' recommendations for promoting a "semi reclined positioning" (Ludington-Hoe et al., 2008; Nyqvist et al., 2010). SDF positioning was also found to reduce the risk of postnatal maternal depression and to promote and prolong SSC sessions

(Buil et al., 2019). Moreover, Buil et al. (2020) tested the kangaroo SDF positioning 18 days after a very preterm birth and showed that SDF positioning improves the mother's ability to perceive her infant's behaviors such as vocalizations, smiles or eyes openings, as well as to respond in a timely manner. Since its creation, other teams have investigated potential benefits of skin to skin in SDF position, either looking at "the influence of a skin-to-skin lullaby on the stability of maternal behavior and on the tonic emotional manifestations of the preterm infant" (Provasi et al., 2021) or at the "vocal responsiveness of preterm infants to maternal infant-directed speaking and singing during skin-to-skin contact (Kangaroo Care) in the NICU" (Carvalho et al., 2019). However, in these studies, observations were not made immediately after birth. Therefore, the essential question of how and to what extent SDF positioning enhances the quality of communication from the start is yet to be examined. In this direction, our team has previously explored touch and maternal vocal behavior during the first skin to skin in a sample of our population. In this position, mothers display more active, securing and affectionate touch, favoring a quality early reunion, free from over-stimulations, as reflected by drowsiness and less agitation in the baby (Buil et al., 2017a). Moreover, from the very first minutes of skin to skin, mothers in SDF provide a denser and more musical sound envelope (Buil et al., 2017b).

Given our current knowledge on the effects of temporal coordination during communication on infant development, particularly in the neonatal period and infancy, the question of mother-preterm communication is decisive. The first minutes of the very first skin to skin are the physical and emotional reunions of mother and child after birth in a potential traumatic context. Nonetheless, current literature regarding the first skin to skin in the NICU focuses mainly on its secure feasibility (Linnér et al., 2020), the moment of and impact on its implementation during hospitalization (Mörelius et al., 2012; Blomqvist et al., 2013), its physiological benefits for the preterm (Cadwell et al., 2018; Gere et al., 2021; Pandya et al., 2021) or parents' feelings (Maastrup et al., 2018). The data collected in this pioneering study shed light on what actually happens between mothers and their babies born prematurely during their first skin to skin.

The present study aimed to better characterize the vocal meeting of the mother and her very preterm newborn, during the first minutes of their first ever skin to skin. We also further examined the immediate benefits of SDF positioning during the first SSC on the quality of mother—very-preterm infant communication. We hypothesized that, compared to Vertical positioning and as early as 3–4 days after birth, SDF positioning would, by increasing opportunities for eye contact, improve the mothers' ability to recognize her infant's signals, thus enabling a more timely feedback. Finally, we aimed to examine how the communicative behaviors of mothers and very-preterm infants were coordinated in time during SSC, just a few days after birth.

Materials and methods

Participants

The study was conducted between May 2015 and June 2016, in a level III NICU at the *Centre Hospitalier Intercommunal de Créteil* (France). Among the 90 very preterm babies (27 to 31 + 6 weeks' gestation) admitted during the inclusion period, 53 met parent and child's inclusion criteria [living in the geographical area considering the longitudinal follow-up, no multiple birth > 2, no neurological complication due to several vascular hemorrhage (IVH grade III, or IV)], no severe medical conditions, no incapacitated physical or psychological illness in the mother. Seven mothers refused to participate, and two inclusions were missed. Among the remaining 44 births, two were lost during follow-up and eight were multiple births which were not included in the present report. The final sample included 34 very preterm infants and their mothers. The first 17 dyads were offered SSC positioning, as usually practiced in the participating NICU (Vertical Control Group). The following 17 dyads were offered the Supported Diagonal Flexion (SDF) Intervention positioning and these were matched to the first 17 dyads on newborns' gestational age at birth and weight at birth (see Buil et al., 2020 for the detailed method). Participants' socio-demographic, Ob/Gyn, delivery and birth data were obtained from medical files.

The present study is part of a longitudinal follow-up from very preterm birth until 3 months corrected age. The data presented constituted the first data collection point of this prospective monocentric matched-pair case-control study. Some data from our study of mother-very preterm communication at 18 days post-partum have already been published in a previous paper (Buil et al., 2020). Measures of the mothers' risk of depression (made before the first SSC session), were comparable for the SDF positioning group and the Vertical positioning group, with EPDS mean scores of 13.8 and 12.9, respectively (Buil et al., 2019).

Skin-to-skin positioning in each group

In the Vertical Control Group, preemies were positioned chest to chest between the mother's breasts, at the center and on the median line of the mother's torso, in an upright position, with a breastfeeding nursing pillow (see Figures 1A,B). According to Kangaroo Mother Care guidelines, the head is turned to one side and in a slightly extended position which keeps the airway open. Moreover, the hips should be flexed and extended in a "frog" position; the arms should also be flexed (World Health Organization, 2003).

In the SDF Intervention positioning (see Figures 1C,D), the baby is naked, off-center and semi-reclined on the mother's chest, chest to chest (Buil et al., 2016). In this intermittent kangaroo mother care, the choice of on which side of the body (right or left) the baby's head is positioned is

FIGURE 1
Vertical control positioning **(A,B)** and Supported Diagonal Flexion (SDF) intervention positioning **(C,D)** during the very first SSC after very preterm birth.

up to the mother. The SDF position is characterized by a slightly flexed body axis, with the limbs retracted in a preventive posture and the head in line with the body axis to prevent side-to-side toppling and to free respiratory permeability (Nyqvist et al., 2010), moderately externally rotated hips in flexion-abduction (Vaivre-Douret et al., 2004), with adducted shoulders (Ferrari et al., 2007). The baby's head is located between the mother's nipple and clavicle and oriented toward the mother's face. His/her arms and legs are flexed, in a naturally adopted asymmetrical tonic neck posture (Casaer, 1979), according to the baby's gestational age and comfort. The baby is positioned on the mother's naked chest, a baby wrap adjusted around the two is used to support and help maintain the baby's posture and to relieve the mother. For the study purpose, we chose The Little-Wrap-Without-A-Knot is a knitted fabric, specially made for Baby Wearing. On one end of the cloth are sewn two metal rings. The Fabric has a special density of 300 gr/m^2. It is made of a two-faced Viscose certified Oeko-Tex 100. The special mechanism of this knitted fabric, allows it to slightly stretch, and to ensure a soft touch that respects the preterm baby's skin. The Little-Wrap-Without-A-Knot is put as a loop around the mother's body. It goes from shoulder to opposite hip and back up to the shoulder, in an asymmetric diagonal. The end of the fabric passes through the rings that creates a buckle effect. This adjustment system ensures a precise fit between the two morphologies and to maintain the desired position of the baby.

In both positionings, the mother was comfortably seated in an adjustable armchair, her back inclined 40°, with a toe-clip, dim light and a quiet atmosphere; she had the choice to wear clothes or not. In SDF Intervention positioning, the baby wrap was placed over the mother's clothes or on her naked chest.

Apparatus

Mother and neonate were filmed during their very first SSC, on average 3.7 days after very preterm birth, i.e., on average 29.4 weeks GA (see Table 1). For each dyad, vocal interaction was analyzed only during the first 5 min. Indeed, mothers were particularly active during the first minutes of SSC care, before giving way to mutual relaxation. Thus, 5 min recordings allowed sufficient data collection, but left plenty of intimacy time to the dyad. Mother-neonate dyads were filmed using a single camcorder mounted on a tripod and sound recordings were obtained using a shotgun microphone. Video and audio recordings were synchronized. The camcorder was placed in front of the dyad, in order to frame the mother's chest and the baby's entire body, as well as their faces.

TABLE 1 Infant's' characteristics at birth and at first skin to skin, according to type of SSC positioning.

	SDF intervention group		Vertical control group	
	N = 12		*N* = 11	
	Mean (*SD*)	*N* (%)	Mean (*SD*)	*N* (%)
Birth data				
Gender				
Girl		8 (67%)		7 (64%)
Weight (g)	1,079 (266)		1,126 (306)	
<1,000		5 (42%)		4 (36%)
1,000–2000		7 (58%)		7 (64%)
Gestational age(w)	29.4 (2.7)		29.4 (2.4)	
<28		3 (25%)		2 (18%)
28 to <32		9 (75%)		9 (82%)
Spontaneous breathing				
Yes		3 (25%)		3 (27%)
Data at first skin to skin				
Age (days)	3.8 (2.0)		3.7 (2.1)	
Weight (g)	994 (203)		1,048 (290)	
<1,000		6 (50%)		4 (36%)
1,000–2000		6 (50%)		7 (64%)

Video and acoustic analyses

Video analysis was performed using The Observer XT with a precision of 40 ms (25 images per second). Vocal data were analyzed with the software Audacity.

Coding of newborns' states of alertness

Newborns' state of alertness was coded with frame-by-frame video microanalysis using the software The Observer XT[1] and following APIB's state configurations (Als et al., 1982): (1) deep sleep state, (2) active sleep state, (3) drowsiness state, (4AL) low awake state, (4AH) high awake state, (4B) quiet awake state, (5) active awake state, and (6) crying state. We included an additional "undefined" category, when the infant's state of alertness could not be coded because the newborn's face and body could not be viewed in the video. Coding was carried out by a perinatal professional with NIDCAP certification (Newborn Individualized Developmental Care and Assessment Program). We recorded the time of onset and duration of each of these states of alertness.

Coding of newborn and maternal vocalizations

Maternal and newborn vocalizations were coded using the software Audacity.[2] Based on the visualization of sonograms and audio guidance, a segmentation into two types of events was made: maternal vocalization and newborn vocalization, (Gratier et al., 2015; Dominguez et al., 2016), both defined as the production of vocal sound that was either continuous or included unvoiced segments of <300 ms. If a pause following an audible vocal sound was >300 ms, two successive vocalizations were coded. Vegetative sounds produced by infants such as burps, growls or hiccups, noise from the environment and vegetative sounds produced by mothers, such as coughs, were not coded. Our criterion was more flexible than that used with full term babies, in order to include more of the preemies' voiced demonstrations.

Coding of turn-taking sequences

A turn-taking sequence was defined as a sequence of vocalizations involving at least one alternation between interactive partners, which is expressed as follows. When more than one alternation occurred, with intervening pauses between the two partners, the number of pauses coincided with the number of turns in the sequence (e.g., two turns: "newborn vocalisation-pause-mother vocalisation-pause-newborn vocalisation"; three turns: "newborn vocalisation-pause-mother vocalisation-pause-newborn vocalization-pause-mother vocalisation" and so on). A turn-taking sequence ended when the same partner produced at least two successive vocalizations, or when the pause following a vocalization exceeded 3,000 ms in accordance with previous studies (Stern, 1985; Gratier et al., 2015; Dominguez et al., 2016; Boiteau et al., 2021).

Training and reliability

A single coder was responsible for coding states of consciousness with the Observer software and two coders for coding the vocal exchange with the Audacity software. None of the coders were aware of the aim and hypotheses under investigation. For this reason, training was performed on randomly chosen dyads both from the SDF and Vertical positioning groups. The training of coders consisted in three steps. First, coders were trained to use the coding template on 4 dyads under the supervision of the researchers. During the second step, each trainee was invited to code 4 additional dyads alone. At the end of this step, the coding was checked

1 www.noldus.com

2 https://audacity.sourceforge.net/

TABLE 2 Sociodemographic, previous obstetrical, and delivery data according to SSC positioning.

	SDF intervention group		Vertical control group	
	N = 12		*N* = 11	
	Mean (*SD*)	*N* (%)	Mean (*SD*)	*N* (%)
Socio-demographic data				
Mothers' age (years)	30.9 (6.4)		30.2 (4.8)	
≥30		9 (75%)		8 (73%)
Living with partner				
Yes		10 (83%)		11 (100%)
Employment status				
Employed		9 (75%)		10 (91%)
Previous obstetrical history				
Gestity before current pregnancy	2.3 (1.0)		2.1 (1.0)	
Yes		9 (75%)		7 (64%)
Parity before current pregnancy	0.47 (0.62)		0.88 (0.99)	
Nulliparous		6 (50%)		6 (55%)
Early pregnancy loss	0.88 (0.93)		0.82 (1.24)	
Yes		5 (42%)		3 (27%)
Late pregnancy loss				
Yes		0 (0%)		1 (9%)
Previous history of preterm birth/LBW				
Yes		1 (12%)		2 (18%)
Current pregnancy				
Hospitalization during pregnancy				
Yes		5 (42%)		11 (100%)
High risk pregnancy				
Yes		5 (42%)		8 (73%)
Intra uterine growth restriction		3 (25%)		3 (27%)
Hypertension/ pre-eclampsia		3 (25%)		5 (45%)
Preterm delivery threat		1 (8%)		4 (36%)
Current delivery				
Spontaneous delivery		0 (0%)		0 (0%)
Labor induction		12 (100%)		11 (100%)
Fetal heart rate abnormalities		8 (67%)		4 (36%)
Intra uterine growth restriction		5 (42%)		3 (27%)
Hypertension/ Pre-eclampsia		4 (33%)		1 (9%)
Delivery type				
Vaginal delivery		1 (8%)		4 (36%)
Caesarean section		11 (92%)		7 (64%)

and discussed with the supervisor. The third step consisted in reapplying the second step.

Twenty five percent of the data set, chosen randomly, was double-coded. Inter-coder reliability (Pearson product–moment correlations) regarding the number of behaviors ranged from 0.82 to 0.92 depending on the behavior. Onset positions were considered identical if they occurred within 80 ms (i.e., two frames); thus, measures of behavior duration had an error tolerance of up to 160 ms. Both coders correctly identified 77.2% of all onset positions within the subset of double-coded sequences.

Ethical considerations

All mothers were offered to participate to the research study on a voluntary basis, within the first 2 days postpartum, and in all cases before the first SSC session. Every mother was informed of the research by a letter in the NICU. Mothers gave a written informed consent before participating. Written informed consent was obtained from the mothers for the publication of any potentially identifiable images or data included in this article. An initial information-based meeting was organized prior to data collection. This research was approved by the French Local Ethics Consulting Committee for the Protection of Persons (IRB n°2015120001072).

Statistics

All analyses were performed using Stata for Windows (version 14; StataCorp). Sociodemographic data, previous obstetrical and delivery data and infants' characteristics at birth and at first skin to skin contact were compared in both groups, with either a *t*-test or a chi-square test, depending on the measure. The number of vocalizations and their duration were analyzed through a general linear model with an adjustment on age and weight at birth. Parametric tests were not chosen considering these measures did not differ significantly from normality.

Results

For 11 dyads, either the baby or the mother did not vocalize during the recorded session of SSC. Analysis of the vocal exchange was therefore conducted on 23 dyads, 11 dyads in the Vertical control group and 12 in the SDF Intervention group. Table 2 presents sociodemographic characteristics, obstetrical and delivery data, and Table 1 infant's data at birth, at first skin to skin, according to SSC positioning. No significant difference was found between the two groups.

State of consciousness

Infants were mainly in a state of drowsiness (state 3), even more so in the Vertical group (58%) than in the SDF group (35% of time). Active sleep state (state 2) represented around 35% of the time in both groups. However, infants in the SDF group also spent 19% of the time in deep sleep (state 1), while those in the Vertical group spent only 3%. In SDF group, infants spent 58% of the time sleeping (states 1 and 2) compared to 36% in the Vertical group. Distributions were significantly different [*Chi-square* (5) = 116, $p < 0.0001$].

Newborns' vocal production

We collected 167 vocalizations: 84 in the SDF group (i.e., on average 7.0 per newborn and 1.4 per minute) and 83 in the Vertical group (i.e., on average 7.5 per newborn and 1.5 per minute, adj $p = 0.90$). Vocalizations' duration was on average longer in the Vertical group (Vertical: 817 ms, SDF: 537 ms), but not significantly after adjustment on birth age and weight (*adj* $p = 0.78$). Consequently, newborns' vocalizations occupied less dialogue space in the SDF group than in the Vertical group (1.3% vs. 1.9% of the 5 min analyzed).

Mothers' vocal production

Overall, mothers vocalized twice more in the SDF group (604, i.e., on average 45.3 per mother and 9.1 per minute) than in the Vertical group (269, i.e., on average 24.5 per mother and 4.9 per minute), but the difference was not significant (*adj* $p = 0.068$). Their vocalizations were on average significantly longer (SDF: 1166 ms, Vertical: 1068 ms, *adj* $p = 0.002$). Hence, Mothers' vocalizations occupied more dialogue space in the SDF group than in the Vertical group (20.1% vs. 8.0% of the 5 min analyzed, $p = 0.007$).

Temporal proximity of mother and newborn vocalizations

Based on a 3-s criterion, 3 preterm newborn vocalizations out of 4 (74%) were at a temporal proximity from a maternal vocalization in the SDF intervention group against 1 out of 2 (47%) in the Vertical control group ($OR = 3.2$, $p < 0.0001$). The difference was still significant when using a 1-s criterion (57% vs. 39%, $OR = 2.1$, $p = 0.017$).

Turn-taking coordination

Based on a 3-s criterion, 73 mother-newborn turn-taking sequences (TTS) were identified: 44 in the SDF group and 29 in the Vertical group. In all, 75 newborn vocalizations were involved in these sequences, i.e., 45% of the total number of vocalizations collected. Almost all sequences were either one turn "baby–mother" or two turns "mother–baby–mother." One third of these were two-turns sequences, sensitively but not significantly more in the SDF group ($OR = 1.4$, $p = 0.56$). When using a 1-s criterion, the number of TTS sequences fell to 65: 36 in the SDF group and 29 in the Vertical group: the odd ratio indicates a 3.8 times higher chance to observe a two-turns sequence rather than a one-turn sequence in the SDF intervention group than in the Vertical control group, but it does not reach significance ($OR = 3.8$, $p = 0.059$).

Discussion

The present study brings pioneer data on the very first skin to skin between mother and her very premature baby. Although novel, analyses conducted in the paper are pilot, the first of their kind.

First meeting: Not necessarily vocal

Our study focused on the very first vocal exchanges, therefore we selected dyads in which both the mother and the baby vocalized (23 out of 34 dyads). It is important to note that during the first 5 min of the first meeting after giving birth, some mothers may have not wished to speak. This very first skin-to-skin is also the very first opportunity for mothers to hold the newborn, with a place for spontaneity as it is a non-medical, non-nursing, and non-guided moment. It is a moment for intimacy, for being together, and not necessarily for speaking. Indeed, during this moment, deciding to speak or not to speak to the newborn was the mother's choice. It seems that this choice was the expression of the mother's preferred way of communicating, the relationship being potentially expressed through other sensory modalities: tactile (Buil et al., 2017a), kinaesthetic, visual.

Better sleep quality

Our results showed that within the first 5 min of the very first skin to skin, very preterm newborns in the "SDF" group spent less time in a drowsy state (state 3), and more in deep sleep (state 1), than those in the Vertical control group. This result suggests that the "SDF" positioning helps preterms stabilize in restorative sleep during skin to skin, rather than stay in a state of drowsiness, considered by some authors as a transitional state, costly in energy (Als, 1982; Brazelton and Nugent, 1995; Bullinger and Goubet, 1999; Foreman et al., 2008; Devouche and Buil, 2019). This stabilization of preterm newborns' state could rely on both an improved postural support thanks to the SDF positioning that fosters the axial winding posture with support on the neck and retroverted pelvis (Vaivre-Douret et al., 2004), but also the active behavioral support of mothers installed in SDF positioning. These

mothers would intuitively help their child into deep sleep, switching rapidly from state 2 to 1, or appease him/her. From the first minutes of this renewed closeness, the SDF positioning could increase mothers' sensitivity to their child's signals of disorganization (such as growling, frowning, wriggling, spreading their fingers, etc.,), allowing them to respond by speaking, nursing or caressing them before they reach full disorganization.

Premature newborn vocal presence

During this moment, that occurred on average at 3.5 days of life, newborns' vocal production did not differ significantly between the two groups, even though vocalizations were on average longer in the Vertical group (before statistical adjustment). Our vocalizations sample was not large enough to allow us to investigate the links between length of vocalizations and states of awareness. However, we believe that the lengthier vocalizations recorded in the Vertical group could be linked to the state 3 that is found in the synactive theory of development (Als, 1982) and characterized by more grunting, which are also probably longer than other kinds of vocalizations. It would be interesting to investigate this further, by characterizing the quality of this vocalization.

One aim of this study was to better characterize the vocal meeting between mother and very preterm newborn, during the first minutes of their first ever skin to skin. Our study provides pioneering data regarding the vocal presence of the very preterm newborn during the first SSC, which represents 1.4 to 1.5 vocalizations per minute for the 23 dyads in which vocalizations did occur, regardless of the positioning. The observed frequency was much higher than that recorded by Caskey et al. (2011), because data was collected at a time dedicated to the relationship, whereas Caskey and colleagues made their recording during several hours in a crib. Vocal displays were scarcer in our very preterm newborns than in healthy term newborns installed for a cuddle in the parent's arms or close to each other [3/min in Boiteau et al., 2021 and 2.7/min in Dominguez et al., 2016], but they were present. Indeed, it is hard to know whether these vocalizations were signs of discomfort or communication, whether they were voluntary or not, and whether they were addressed or not. Their mere existence, despite infants' immaturity, parents' feeling of unease and the hypermedicalization of these first moments, provides an opportunity to establish communication.

Maternal vocal envelope

Our results showed a denser vocal presence in the SDF group than in the Vertical group (20% vs. 8%), with longer vocal interventions. This longer exposure to the mother's voice might be important according to a recent literature review highlighting its positive impact on parenting skills (Filippa et al., 2019). This result supports the hypothesis that SSC in SDF positioning enhances and supports early vocal contact. This strategy is now recognized as a new and important Infant- and Family-Centered Developmental Care (IFCDC) strategy for the benefit of preterm infant brain development (Filippa et al., 2017; Monaci et al., 2021).

This clearly denser maternal vocal envelope could be perceived as over-stimulating for a 3–4-day preterm newborn. The SDF positioning was not conceived to promote "more" (as in "too much") but rather "better," closer to what would be the first meeting with a healthy term newborn. Here, judging by the analysis of the newborn's states of consciousness, it seems that these behaviors were not perceived as over-stimulations. This question could be further explored by investigating the links between maternal voice and states of consciousness, as it was done by Filippa et al. (2018) or Saliba et al. (2020).

Temporal coordination

In our pilot data collection, we tried to investigate the vocal temporal coordination between the mother and her very preterm newborn as Dominguez et al. (2016) and Boiteau et al. (2021) did with term-newborns. However, the few vocalizations recorded only allowed a timed analysis. Although no difference was found between both positionings regarding the amount of newborn vocalizations involved in turn-taking, descriptive results suggest more complex turn-taking in the SDF intervention group. Although not significant, this result is consistent with the denser vocal presence of mothers. We hypothesized that being more able to see the face and perceiving their newborn as an available partner, mothers in the SDF group were more likely to vocalize in a timely manner and thus create the very first vocal exchange with their baby.

Furthermore, based on a 1-s criterion, 57% of the preterm newborn vocalizations were at a temporal proximity of a mother's vocalization in the SDF intervention group against 39% in the Vertical control group. Hence, our results show that mothers in the SDF intervention group provided a more proximal vocal envelope, but far from the 95% observed by Dominguez et al. (2016) in mothers of healthy term babies. By nature, full-term infants require the intervention of competent adults, and in this sense, it is not relevant to oppose the "natural" lives of term infants with the "unnatural" lives of hospitalized infants (Gratier and Devouche, 2017). Environments are constructed around infants but more importantly, infants, from the earliest moments of their lives, participate in this construction. The present study adds to the current knowledge and understanding that preterm infants respond to their environment too. Our results plead for more reflection on how to better adapt the environment, so that in turn, it responds to the premature baby.

Developmental perspectives

Dyads observed in the present study were followed during the first months of life and data collected at 18 days of life, i.e., 15 days

after the very first SSC have already been published in a previous paper (Buil et al., 2020). At birth, preemies in both groups did not differ in their vocal production, the main results being that mothers provide a more proximal and denser vocal envelope. Two weeks later, in the SDF Intervention Group, very preterm infants vocalized three times more, mothers vocalized, gazed at their baby's face, and smiled more than in the Vertical Control Group, and temporal proximity of mother-infant behaviors in a one-second time frame was greater in the SDF Intervention Group (Buil et al., 2020).

The present study and the previous one plead in favor of a positive impact of a more comfortable positioning, that allows visual contact for mother-preemie interaction from the very beginning. Indeed, when offered more opportunities to be connected, mothers tended to engage more in the communication. Being able to perceive key behaviors such as open eyes, mouth movements, or being able to understand a vocal manifestation because they have a better perception of the whole story, mothers are more responsive from the very beginning. Thus, because primary intersubjectivity had the possibility to develop and so had the dyadic space (Trevarthen, 1998), mother and preemie were more able to meet and communicate 2 weeks later.

SDF positioning not only influences positively infants' states of consciousness and mothers' availability, thus fostering communication. Indeed, what seems to matter the most is the mother's responsiveness, her ability to perceive the availability of her very preterm newborn to interact (Ainsworth et al., 2015) and to adjust her behavior at the level of body tonus and emotion (Ajuriaguerra, 1986).

Long-term perspective: Supporting the preemie, the mother and the father, and a timely adjusted communication during SSC

Given the persistence of difficulties in parent-infant synchrony at 3 (Feldman and Eidelman, 2007) and 6 months GA (Forcada-Guex et al., 2011) in preterm contexts, offering SSC to support communication between the preemie and his parent as soon as possible after birth is essential. Feldman et al. (2014) pointed out that any attempt to encourage mother-infant proximity could help fragile babies and their parents to develop optimal synchrony before the end of the sensitive period. Practicing SSC with SDF positioning, rather than SSC as it is widely practiced today (Vertical positioning), offsets the paucity of parent-infant communication related to preterm birth, by enhancing both partners' production and detection of multimodal signals, as well as their temporal coordination. Our results highlight the possibility of mother—very preterm baby vocal exchanges during skin-to-skin, especially with SDF positioning, as early as 3/4 days after birth.

The literature shows that mothers present a left side bias for carrying their baby (Donnot and Vauclair, 2005; Malatesta et al., 2019), which seems particularly stable during the first 3 months of the child's life, regardless of culture and time (Malatesta et al., 2019). These two studies noted correlations between carrying bias and maternal empathy as well as mother's capacity to engage emotionally in a relationship (Donnot and Vauclair, 2005; Malatesta et al., 2019). In the present study, five mothers out of 17 spontaneously chose to carry their newborn on the left side of their body during the first SSC. Hence, by allowing mothers to choose on which side their wish to carry their child each time a skin-to-skin care is proposed, SSC in SDF positioning is indeed a natural precocious way to support intuitive parenting (Papoušek and Papoušek, 2002).

In their article on the eight principles to follow in NICU, Roué et al. (2017) highlighted the need for a free 24 h/24 parental access and a psychological parental support. In their conclusion they recalled the need for future researches in this direction. More recently, Filippa et al. (2021) published a systematic review on the benefits of involving the fathers of preterm infants in early interventions in neonatal intensive care units. Their conclusion was in line with Roué et al.'s recommendations by stressing the need to develop new, multimodal and interactive interventions that provide fathers with positive contact with their preterm infants. Indeed, few studies were conducted on early father-preterm communication. However, as Boiteau et al. (2021) showed, the father and the baby meet as of the birth, why not the father and the (very) premature newborn? Benefits of SDF positioning could thus be appreciated through daily practice with fathers in NICU.

SDF positioning could promote brain-to-brain synchrony during naturalistic social interactions (Kinreich et al., 2017). SSC is described as the only developmental care dedicated to dyadic interaction (Buil, 2019), but this appears all the more obvious when both partners manage to meet (even briefly), by making eye contact, smiling and vocalizing. Even though long-term benefits of SDF positioning are yet to be investigated, our results, although based on pilot data, pleads in favor of a modification of current skin-to-skin contact practices with very preterm babies.

Limitations

This pilot study presents some limitations. Additionally, to the number of dyads included ($N = 34$) which in itself limits the range of our results, our study was conducted in one unique level 3 NICU. A random allocation of dyads in SSC positioning would have been more optimal and would have strengthened our study design, but it would have created a risk of practice contamination. The safe implementation of SDF positioning in NICU needs to be further examined by conducting a multicentric study based on randomized sampling and including a larger group of extremely preterm infants and/or unstable very preterm infants requiring endotracheal ventilation.

Conclusion

Very little is known about what happens between the very preterm and the parent during skin-to-skin contact, despite it being the only care entirely dedicated to the parent–infant relationship in NICUs. Seeing very preterm newborns open their

eyes, attempt a smile or hearing their vocalizations are rare and short-lived moments. Yet they are essential moments, because they reveal the preterm as a fully-fledged individual, who communicates, despite immaturity and uncertain vital and developmental prognoses. They are also essential when infant and parents meet for they contribute to the creation of the first bonds.

Our study showed that whatever the positioning considered, and although we only analyzed the first 5 min of SSC in a sample of 23 dyads, very preterm newborns were able to vocalize. Indeed, during SSC, i.e., in a moment dedicated to intimacy, the very preterm newborn was vocally present and provided opportunities to establish communication. Moreover, SDF positioning supported mothers' vocal responsiveness to the vocal presence of their newborn, thus fostering the beginning of adapted and coordinated vocal responses, and feeding intersubjective intimacy.

Providing early communicational pathways for parents and very preterm infants, as early as possible, enables initial interactive experiences, providing a less atypical, less dysregulated, and more consistent environment. Our pioneer data sheds light on the way a mother and her very preterm vocally meet, and constitutes a pilot step in the exploration of innate intersubjectivity in the context of very preterm birth. Future studies are needed to explore other ways by which the very preterm connects to his/her partner, thus creating a dyadic intersubjective space, i.e., vision, tonic postural dialogue, rhythm, touch, and olfaction.

Data availability statement

The datasets presented in this article are not readily available because it contains sociodemographic and medical information that cannot be shared consistently with GDPR requirements. Requests to access the datasets should be directed to devouche7@gmail.com.

Ethics statement

All mothers were offered to participate to the research study on a voluntary basis, within the first two days postpartum, and in all cases before the first SSC session. Every mother was informed of the research by a letter in the NICU. Mothers gave a written informed consent before participating. Written informed consent was obtained from the mothers for the publication of any potentially identifiable images or data included in this article. An initial information-based meeting was organised prior to data collection. This research was approved by the French Local Ethics Consulting Committee for the Protection of Persons (IRB n°2015120001072).

Author contributions

AB and ED contributed to the conception and design of the study and wrote the first draft of the manuscript. AB collected the data. ED performed the statistical analysis. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Loneliness and intersubjectivity: A view from Trevarthen's theory

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1. Introduction

Based on his pioneering research on infants and drawing from the epistemological framework of phenomenology (Husserl, 1964; Habermas, 1972), Trevarthen has formulated a developmental theory of *intersubjectivity* which focuses on innate Other-awareness, inborn motives for sympathetic engagement with others, and cultural sharing—from the beginning of life (Trevarthen, 1977, 1980; Trevarthen and Aitken, 2001). I suggest that this theory of companionship has the potential to offer a rich conceptualization of *loneliness*, defined as the distress and social pain stemming from being alone. This potential has not been examined thus far and is the focus of this study.

2. Loneliness as a social or relational emotion

I suggest that within Trevarthen's theory of intersubjectivity loneliness can be regarded as a complex and dynamic *social* or *relational emotion* (a term introduced by Stern, 1993). It is an emotion between persons, a fellow-feeling, according to philosopher Adam Smith (1759), who inspired Trevarthen.

Social or relational emotions belong to the *causes* of consciousness, according to Trevarthen (2005a). This may apply to loneliness too and contrasts with the long-standing interpretations of loneliness as an outcome of cognitive processes, that is, of individuals' awareness of their relational (quantitative and/or qualitative) deficits, which, in turn, stems from the perception of the dissonance between the expected and the real level of relationships (e.g., Peplau and Perlman, 1982). Cognitive models of loneliness place emphasis on *subjective* cognitions as the source of loneliness. In the intersubjective framework, the order is reversed: social emotions are the causes of co-consciousness, of self-other awareness.

Loneliness is a universal experience with cognitive, emotional, contextual, and motivational dimensions (e.g., Galanaki, 2004). From an evolutionary and attachment viewpoint, it has been conceptualized as a proximity-promoting mechanism with a survival value for the human species (Cacioppo and Patrick, 2008). However, the theory of intersubjectivity has the potential to place loneliness over and above attachment (protection, comfort, and care) and survival. Thus, loneliness may be regarded as expressing not only attachment for care but also *attachment for companionship* and as arising and being alleviated within a *circle of attachments* (Trevarthen, 2004a, 2005c). In this line of thought, loneliness originates from humans' *social brain* (Dunbar, 2009), *allocentric perception* (Bråten, 2009), and innate *dialogicity* (Wertsch, 1991).

3. Loneliness as a moral emotion

Further, I suggest that, as a motive for *sympathy*, loneliness belongs to our moral core and can be regarded as a *moral emotion*. Unlike empathy, which is rather one-sided, sympathy is the intersubjective awareness of agency and emotion that works reciprocally between persons (Reddy and Trevarthen, 2004; Reddy, 2008) and reflects complementary emotional states that are shared with the other. It is a bridge between persons expressing their mutual assistance (Trevarthen, 2013). Sympathetic persons have moral emotions, such as pride and shame, that "can keep or break social ties, and may facilitate sharing of meanings and purposes, or make their understanding more difficult" (Gratier and Trevarthen, 2007, p. 173). Specifically, Trevarthen (2005c, p. 77) links shame and loneliness by stating that "shame in failure [. . .] threatens loss of relationship and hopeless isolation."

Aloneness carries stigma and signifies rejection, exclusion, and ostracism. This is often an *exclusion from meaning* (Trevarthen, 2005c). Therapists must keep in mind that we are born with readiness to join in kindness and playful sympathy with companions (Trevarthen, 2019). Thus, *loneliness of shame* (Trevarthen, 2022) may be the target of prevention and therapy from the beginning of life.

4. Loneliness as an innate intersubjective motive

If emotions and motives have strong links with each other or even overlap (Trevarthen, 1993), I suggest that loneliness can also be conceptualized as an *innate intersubjective motive*—a motive for seeking human company. Loneliness stems from absence and is regarded as longing for something missing. The desire to transform absence into presence—the *compulsion to share* the time of movement (Trevarthen, 2009)—may be what distinguishes loneliness from clinical depression (however, intense loneliness may appear as a symptom of clinical depression and take on several qualities as a function of the type and severity of depression). In depression, motives for life and companionship as well as hope for the future seem to suffer. Therefore, loneliness is a *measure of companionship*, not separateness (Trevarthen, 1998). It is "foundational in developing human relations, and in the growth of a sense of individuality or identity in society"—this is Trevarthen (2002, p. 175) view for the emotions of pride and shame.

If emotions are *reflective*, "in the sense that their usefulness for each individual depends on what emotional signals come back from other individuals" (Trevarthen and Aitken, 2003, p. 9) and we can mirror each other's emotions, a person's loneliness *move others*. All emotions can evoke responses in sympathetic others (Reddy and Trevarthen, 2004). Therefore, I suggest that one's loneliness may be painful for all sympathetic others too but also that it is more tolerable by the lonely person who can share it. Furthermore, loneliness in one person can change the emotional state of the other (the sympathetic) person. Nevertheless, the phrase "in one person" is not accurate, because loneliness floats in-between persons, even though it is felt as a highly private experience.

If motives are *observable* (Trevarthen, 1998), it is possible (although not always easy) to detect when others are lonely and seek company. And if motives are transferred and used co-operatively, we can be invited by others to enter their loneliness and contribute to its alleviation.

5. The origins of loneliness and solitude

Regarding loneliness, if infants have feelings like ours (Trevarthen, 2005a), they are bound to have this experience, although they cannot use language to convey it. This may be one reason why their loneliness is neglected by researchers. Trevarthen (2005a, p. 62) wonders: "What causes an infant to display rage or sad withdrawal in a relationship that is not working as expected, and why does a contented infant's mind hide behind a silent mask of inwardness, apparently inventing thoughts?" A fear of an unsupported loneliness is considered typical of the newborn child (Trevarthen, 2003). A baby can express sadness when alone and in need (Trevarthen, 2005b, 2015) and loneliness is one of the outcomes of insensitive, neglectful, or intrusive parenting (Trevarthen, 2014). Trevarthen does not place much emphasis on infants' separation anxiety, which has been regarded as fear of loneliness (Bowlby, 1973; Quinodoz, 1993), perhaps because of his critical attitude toward attachment theory (Trevarthen, 2005c).

Furthermore, solitude is an experience related to loneliness, yet also distinct from it. It is usually conceptualized as *time alone* and as a *state of mind*, rather than a state of being [i.e., it may or may not include physical separation (Coplan et al., 2021)] and is described as a *paradox* because, although it can be self-enhancing, it may lead to loneliness (Galanaki, 2005, 2021). Although Trevarthen (2004b) stresses that there are no single infant heads, he states that even very young infants are capable of disengagement and detachment from sharing of impulses and feelings with other human beings and often withdraw into a solitary state of thinking, reflection, and *contemplation* (Trevarthen, 2011a). It is a state of *self-synchrony* which includes body movements, facial expressions, and vocalizations (Trevarthen, 2011a) and reflects a third type of *motive* (the other two are communicating with persons and doing with objects; Trevarthen, 1998). This inward or self-directed motive has been neglected by infant research (Trevarthen, 1998). Private thinking and social communicating co-exist in corresponding and complementary ways from the beginning of life. The minds of mother and infant are together while having their separate recollections and purposes and while sharing these reflective, meditative states (Hobson, 2002; Trevarthen, 2005a). I would call this shared experience of mother and infant *solitude à deux* and I suggest that, if sympathy means *respect* for the other person's autonomy even when there is disapproval (Trevarthen, 2005c), it is the sympathetic mother that sets the stage for her child's life-long capacity to benefit from solitude. The mother's respect for her child's autonomous ingenuity and invention—this respect is also an educational value (Trevarthen, 2011b)—echoes (Winnicott's, 1965) statement that the *capacity to be alone in the presence of the mother* is a major developmental achievement.

6. Implications for the causes and the alleviation of loneliness

Trevarthen's research and theory of intersubjectivity have the potential to offer a deeper understanding of the causes and, therefore, the alleviation of loneliness. Throughout life loneliness results from a *failure in intersubjectivity* and is reduced when *meaningful sharing* is restored and maintained.

More specifically, first, loneliness may arise when one is *literally* alone. Then, real time engagement with a partner in a dialogue is not possible. The needs for companionship, sharing of vitality, joy, and pleasure are not satisfied. The *actual Other* is missing and the *implicit* or *virtual Other* (Bråten, 1992) is inadequate or the actual Other is missing for a long period. Within the epistemological framework of phenomenology (e.g., Heidegger's being-with-others, Husserl's transcendental intersubjectivity, and Merleau-Ponty's intercorporeity), prolonged and imposed solitude, as a privation of primary and secondary intersubjectivity, throughout life, is a severe *existential* disruption, because it undermines our very constitution—the relational self—and, thus, leads to disturbances in the sense of realness (Gallagher, 2014).

Second, loneliness emerges from the imperfections or distortions of *co-regulation* with partners, from lack of harmony. Trevarthen often uses the terms *mirroring* (Winnicott, 1971) and *attunement* (Stern, 2000) to describe this co-regulation. "Reading" the Other and being "read" by the Other is impaired in loneliness. Our initiative, as an invitation and provocation of the Other, is not reciprocated. Our anticipation is frustrated and our offerings (initially, as research has shown, in imitation and proto-conversation; Murray and Trevarthen, 1985; Kugiumutzakis et al., 2005; Kugiumutzakis and Trevarthen, 2015) are not acknowledged. No loving voice is heard or there is no one to hear our voice (perhaps because of mother's own sense of loneliness and not belonging; Gratier et al., 2015) and to reciprocate our gaze and touch. There is a failure to participate in shared time (Trevarthen, 2016). *Synrhythmia*—the Greek term that Trevarthen et al. (2006) used to capture the graceful poly-rhythmic resonance with the Other and expresses our innate communicative musicality (Malloch and Trevarthen, 2009)—is lost.

Third, I suggest that *distortions of sharing* may be mutually related to loneliness. Optimal sharing of emotions, motives, interests, purposes, actions, etc. is regarded to reflect a balance between engagement and disengagement. When disengagement is more or less than desired, loneliness emerges. These difficulties in self- and co-regulation may manifest as conflicts regarding whether to share or not to share; what to share and what not; when, where, in what pace and with whom to share. In other instances, sharing is asymmetrical or the partners' expectations for the amount of sharing do not match, or sharing is excessive (i.e., one feels "transparent" in an encounter). When chronic and intense, loneliness, in turn, may lead to distortions of sharing. For example, in less fortunate cases, the motivational force of loneliness is not so strong as to facilitate the sharing of our loneliness story with others or, even more, the sharing of the *illusion of sharing* (Kugiumutzakis, 2012; see also Reddy, 2008).

Fourth, because of the distortions of sharing, we cannot co-create *meaning*. Acts of meaning (Bruner, 1990) are impeded or discouraged. Meaning is created when we participate in *emotional narratives* with the Other (starting early in infancy; Stern, 2000) and these embodied narratives gradually become social schemas with cultural significance (Delafield-Butt, 2018). Trevarthen (2004b, p. 23) states that the search for meaning "can fall prey to fear and distress, loneliness and self-doubt." From the beginning of life, we crave for reliable and affectionate others who can sustain the memories we created with them. Sometimes, however, we cannot draw from treasured memories of a special relationship (Trevarthen, 2008), perhaps because there are no such memories, or we cannot sustain the co-discovered memories. In loneliness, we are not meaningful to a significant Other (initially, less fortunate infants are not meaningful to their mothers in the mother-infant proto-conversation).

Finally, apart from the presence of an actual Other, synrhythmia, sharing and co-construction of meaning, it is *cultural membership*, that is, finding one's place in the world as a doer and knower (Trevarthen, 2004b), that reduces loneliness. In the cultural context (initially, the mini-culture of the mother-infant dyad), we satisfy our social curiosity by sharing mental spaces and thoughtfulness. We find sympathetic and trusted partners to share our stories and our sense of beauty (Trevarthen and Delafield-Butt, 2017). "Loneliness, shame, depression and sadness are the emotions that identify loss of this *collective story-telling*, which can be called 'socionoesis'" (Trevarthen, 2013, p. 204; see also Delafield-Butt and Trevarthen, 2015). But if we manage to co-create a narrative about cosmos and feel our co-existence in *symbolic* and *collaborative awareness* (Trevarthen et al., 2006) and our contribution (doing and knowing) is valued by others, *cultural learning* is facilitated and *pride in meaning* (Trevarthen, 2001), instead of shame, is felt. Trevarthen (2004b, p. 36) suggests that "all human cultural achievements arise shared meanings, even when they appear to be lonely products, of creatively dreaming or of adventurous risk-taking in thought or action". To conclude, loneliness arises in a community of minds and is moderated by cultural membership and cultural sharing.

Author contributions

The author confirms being the sole contributor of this work and has approved it for publication.

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Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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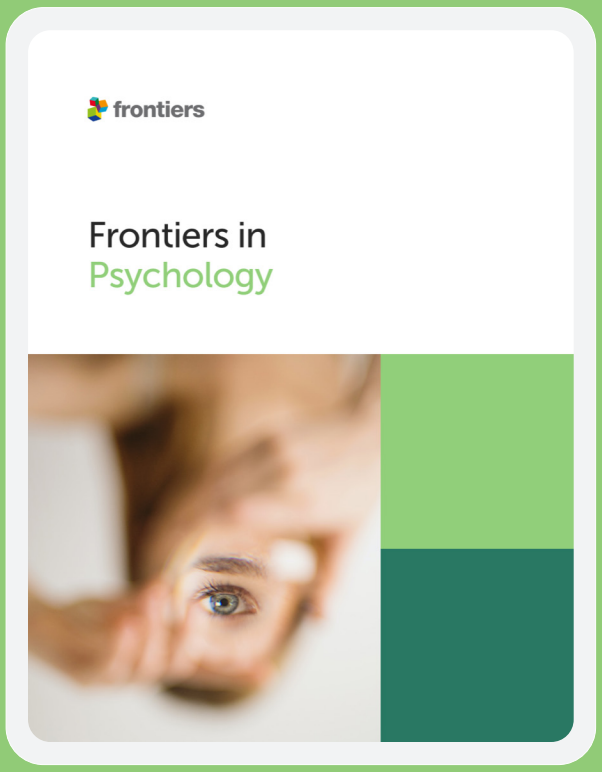

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