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Exploring the Infant Social Brain: What's Going on in There?

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ABSTRACT

Advances in neuroscience allow researchers to uncover new information about the social brain in infancy and early childhood. In this article we present state-of-the-art findings about brain functioning during the first 3 years of life that underscore how important social interactions are to early learning. We explore learning opportunities that occur during everyday interchanges between adults and infants and how these influence the brain. We also examine longitudinal data to understand how children's earliest social interactions set the stage for school readiness and lifelong learning.

A symphony of neural activity erupts in an infant's brain in response to the sound of her native language or a touch on the hand. New, powerful brain imaging techniques now allow researchers to visualize this neural activity, using safe, non-invasive technology. For the first time, scientists are able to witness what happens inside the brain as the baby looks at a person, hears a voice, or experiences a touch to the skin. Researchers are uncovering previously invisible brain mechanisms that underlie and support the visible behavior of babies. These discoveries linking brain and behavior are deepening the understanding of cognitive and social-emotional development, revising long-standing scientific theories, and addressing useful practical applications.

In this article we review the importance of social interactions to early learning. From the moment of birth, humans are primed to seek and respond to social partners around them. Research continues to demonstrate that rapid infant learning happens in the context of these rich social interactions. Scientists seek to isolate segments of this interaction so as to understand the fundamental brain and psychological mechanisms involved. In fact, the latest science of child development allows researchers to peel away the layers of social interactions to look at component parts. In this article, we analyze some of the newest discoveries and explore the potential for learning within the coos, glances, and gestures that occur before spoken conversations take place. Finally, we examine longitudinal data to understand how these early experiences prepare children for school, connecting the dots from early learning to school readiness.

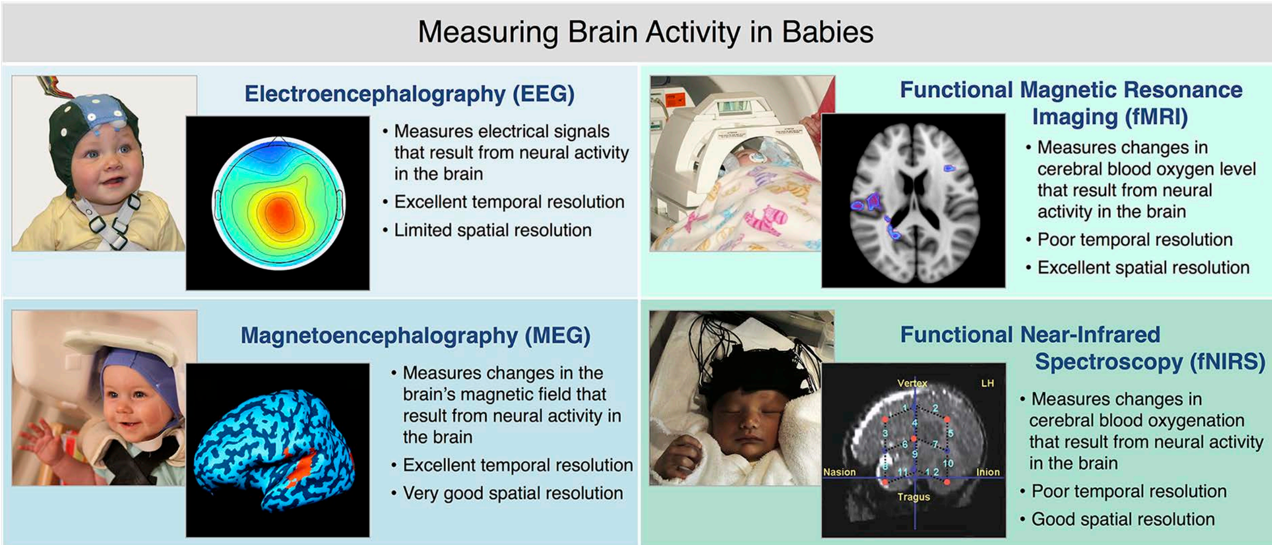
Visualizing the Developing Brain: Infant Brain Science Techniques

How do researchers uncover what's happening inside the baby's brain? Neuroscientists use four main tools to explore the infant brain: electroencephalography (EEG), magnetoencephalography (MEG), functional magnetic resonance imaging (fMRI), and functional near-infrared spectroscopy (fNIRS; see Figure 1).

EEG measures the electrical activity that results from neurons firing in sync. To measure this activity, a snug cap fitted with sensors is placed on an infant's head while they listen, look, or touch. The sensors record the brain's electrical activity during these tasks. EEG is an excellent tool to monitor infant brain activity millisecond by millisecond, but it is not as accurate in showing where the activity occurred. If one thinks in terms of "time and space," one would say: EEG has excellent *temporal* resolution but not very accurate *spatial* localization of the source of the neural activity.

Magnetic resonance imaging (MRI) is used to take detailed pictures of the brain's structure. This technique can be used to compare how the brain's structure develops over time. A closely related technique is called fMRI, which shows the brain's structure, but also provides detailed information about brain activity. Unlike EEG, fMRI does not directly measure electrical activity; it measures changes in the blood's oxygen level, which alters when the brain is active. Although fMRI provides very good spatial information about where brain activity is occurring,

FIGURE 1. **Four brain science technologies used with infants and toddlers.**



it does not provide precise timing information about when the brain activity occurs (changes in neural activity happen in milliseconds, but the blood-oxygenation changes that they induce are spread out over seconds). fMRI is challenging to use with infants because it is noisy, and infants must remain perfectly still to collect a clear picture of the brain. Some researchers use fMRI while children are sleeping, but that restricts the type of research questions that can be addressed.

fNIRS is related to fMRI but is far less expensive, is portable, and allows some movement in the infants. This technique measures hemoglobin concentration in the blood flowing to different areas of the brain, which provides very good spatial information about which areas in the brain are active. Because blood changes are slower than the actual underlying neural activity, fNIRS, like fMRI, does not pinpoint exactly when in time things are happening in the brain. This technique can be combined, however, with EEG to provide even more detailed temporal information.

MEG is another brain-imaging technique that can be used with young babies, and it promises to change the field. By detecting changes in the magnetic field caused by minute neural electrical activity, MEG reveals, to the millisecond, which areas of the brain are at work, and it can do so with great spatial precision. The MEG brain-imaging device provides both timing and spatial information, is perfectly safe, and allows the infants to move. This technology can be used to reveal the dynamic brain mechanisms that underlie the cognitive, linguistic, and social-emotional development during the earliest years of life.

Combining MEG with other tools that reveal the brain's structure, including diffusion tensor imaging (which illuminates the developing bundles of connections forming in the brain), researchers now can obtain a better picture than ever before about infants' brains and how they respond. A child is born with 86 billion neurons, most of the neurons they will ever have. But those 86 billion neurons haven't yet formed all of the trillions of connections that make up the human brain. During the first few years of life, these billions of neurons reach out to other neurons, each with multiple connection points that will be systematically shaped and reshaped by the experiences of a child's life as well as maturational growth. During infancy and early childhood, the brain shows an extraordinary ability to change with experience, and this is called *neuroplasticity*, indicating that the young brain is highly malleable and open to revision. Neuroplasticity presents an important opportunity. The experiences children have literally shape their brains. Their brains are built in part through the experiences they have, including the social experiences they receive from interacting with adults.

Learning Your Native Language: The Power of Social Partners

Infants are born *citizens of the world*, able to make out the difference between all the fundamental sounds, or phonemes, in all the languages around the world. As they grow and become immersed in their native language (or languages), they become *native language specialists*: by 12 months old, there are measurable differences in an infant's ability to distinguish sounds (Kuhl et al., 2006). While they improve at differentiating sounds in their native language, infants lose the ability to distinguish sounds from foreign languages. However, children raised in bilingual households can discriminate between sounds in both of their languages (Garcia-Sierra et al., 2011), which shows the learning that occurs when exposed to two languages.

In a recent study in our lab, we used MEG to peer inside infants' brains as they learn the fundamentals of language. We found that baby brains actually lay the groundwork for forming words long before they speak (Kuhl, Ramírez, Bosseler, Lin & Imada, 2014).

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From the moment of birth, humans are primed to seek out social partners around them, and to thrive from social interaction.

Seven- and 11- to 12-month-old infants listened to a series of native and foreign language syllables such as *da* and *ta* while in the MEG machine. The younger infants showed brain activity in several regions including an auditory area of the brain called the superior temporal gyrus, as expected—but also in Broca's area and in the cerebellum, regions responsible for planning the motor movements required for speaking. This brain activation pattern occurred for sounds in both the child's native language (English) as well as in a non-native language (Spanish), demonstrating that the brains of very young infants respond similarly to all speech sounds, regardless of whether they've heard the sounds before. But brain activation in older infants was different. By 11–12 months old, the motor areas of the brain were more active while listening to non-native speech than when listening to native speech sounds. We think this is because these areas of the infant brain are rehearsing motor plans while listening to speech, and trying to do this for foreign sounds is more difficult.

These activity patterns reflect how early experiences affect the developing brain. As infants listen to language, brain areas that coordinate and plan motor movements become activated by speech sounds, even before infants talk. These findings suggest that infant brains rehearse the mechanics of speech in preparation for their first words. These results highlight the value of engaging children in social interactions, even if they do not yet talk back.

To investigate the role that social interactions plays in language learning, we also invited monolingual, English-learning 9-month-old infants into the lab and exposed them to Mandarin Chinese over twelve 25-minute sessions. Some infants spent these sessions with a native Mandarin speaker as she sang songs, read books, and played. Another group watched a recording on TV of the same sessions but didn't experience the live interaction. A third group simply listened to audio recordings from the sessions. A fourth group served as a control and heard only English during otherwise identical sessions. Remarkably, infants who played with the live Mandarin speakers were just as good at discriminating sounds in Mandarin Chinese as were infants raised in Taiwan, where Mandarin is the native language. However, infants exposed to video or audio recordings alone showed no learning—they were identical to the control infants who heard no Mandarin (Kuhl, Tsao & Liu, 2003). These findings suggest that social interaction "gates" language learning, allowing the infant's brain to process sounds and words, learn their subtleties, and remember them for later use (Kuhl, 2007, 2011).

THE BENEFITS OF "PARENTESE"

As adults interact with babies, many naturally adopt a sing-song style, cooing "Ohhhh myyyy! Whaaaat a biiiiiiig smmmiile you haave!' This exaggerated speech, called *infant-directed speech*, or *parentese*, is a valuable piece of the social interaction puzzle. In general, very young babies prefer to listen to speech sounds over other non-speech sounds (Vouloumanos & Werker, 2004) and prefer infant-directed speech to typical, or adult-directed speech (Fernald, 1985; Fernald & Kuhl, 1987).

Our research suggests not only that infants have definite auditory preferences, but that this style of speech may actually help them learn. Infant-directed speech elongates vowels, extending them over a longer period of time. This stretching makes the acoustic differences between the sounds more distinct, while keeping the fundamental linguistic elements intact (Liu, Tsao, & Kuhl, 2007). Infants (6–8 and 10–12 months old) whose mothers use more parentese are better at discriminating speech sounds (Liu, Kuhl, & Tsao, 2003). Moreover, the more parents use parentese to their 11- and 14-month-old infants, the more the infants babble. One year later, at 2 years old, those same infants had larger vocabularies (Ramírez-Esparza, García-Sierra, & Kuhl, 2014). Parentese appears to be most effective when parents interact with children one-on-one. The more back-and-forth exchanges that occur, the more opportunities for infants to learn language. How adults talk to infants, not just how many words they say, is a fundamental component of their language learning.

BACK AND FORTH: CONTINGENCY IS IMPORTANT

Contingency, or the back-and-forth style of interactions that draw in both partners, is another component of high-quality social interactions. Infants are drawn to contingent responses very early in life. As early as 4 months old, infants prefer an adult who responds contingently to an adult who does not (Hains & Muir, 1996). Children's preference for contingent interactions extends into toddlerhood (Goldstein, King, & West, 2003), and it aids in the development of prosocial behaviors (Thompson & Newton, 2013) as well as word learning (Tamis-LeMonda, Bornstein, Baumwell, & Melstein Damast, 1996).

Contingent social interactions may even help children learn language from screen media. Typically, children younger than 3 years have difficulty learning language from video (Krcmar, Grela, & Lin, 2007). Evidence suggests that lack of contingency in videos contributes to this difficulty. One study investigated whether 24- to 30-month-olds can learn language from a video chat (Roseberry, Hirsh-Pasek, & Golinkoff, 2014). Although video chats, like videos, present speakers in only two dimensions, it mimics live social interactions: A child and speaker can participate in a two-way exchange. In the study, children learned new verbs through video chats just as well as from live social interactions, but they showed no evidence of learning when they passively watched a video.

It may be possible to design improved or different screen devices that respond contingently to children and can participate in some form of "interaction." In fact, research with robots is beginning to be used in laboratories to investigate the important role of contingent social behavior in children's learning (Meltzoff, Brooks, Shon, & Rao, 2010). For example, when robots orient their heads toward 18- to 24-month-old children and name a toy in Finnish, English-speaking children follow the robot's eye gaze and learn the Finnish names for common objects (Kuhl, 2011; Meltzoff, Kuhl, Movellan, & Sejnowski, 2009). Researchers are continuing to explore what features attract babies' attention and engage their learning mechanisms, especially for language.

Looking Toward the Future: The Importance of Eye Gaze

Imagine that you are an infant, immersed in a sea of sounds, trying with all your might to figure out what in the world is going on. What cues could you use to stay with the conversation? Eyes provide a great deal of information; where people are looking can reveal other people's attention, desires, emotions, goals, and likely future behavior. Infants rely heavily on nonverbal social cues like eye gaze as they learn about the social and physical world.

Infants aren't born understanding that following someone's gaze can provide useful information. When do infants understand that eye gaze connects a looker with their environment? When do infants follow others' gaze as they look at interesting objects and events? Our laboratory developed a game to answer this question. Toddlers sit across from a researcher and watch as she turns her head toward one of two identical objects placed on either side of a table. The researcher first looks at the child, then turns to look at one of the toys. For some infants, the adult turns to face the object with her eyes open. For other infants, the adult turns with her eyes closed. If a child understands that people can only see things with their eyes open, they should follow only the adult who turns to the toy with open eyes. This is exactly what happens for infants at about 12 months old: They look at the toy more consistently when the experimenter's eyes are open compared to when her eyes are closed (Brooks & Meltzoff, 2002; see Figure 2).

But how sophisticated is this understanding of eye gaze? What if the researcher's view of the world is blocked by an inanimate device and not their own eye closure? What if it is blocked by a barrier, wall, or blindfold? While 12-month-olds understand that closed eyes can't see, they fail to recognize that a blindfolded researcher can't see, and mistakenly follow the researcher's head turn (Brooks & Meltzoff, 2002). Why do infants understand closed eyes block the researcher's view, but not blindfolds? We hypothesized that this is because infants have more experience opening and closing their own eyes than with blindfolds and could better understand what eye-closure meant when other people did it.

This hypothesis led to a new experiment. We gave another group of 12-month-olds experience with cloths that could act like blindfolds: we raised and lowered the cloth several times in front of the child, blocking their view of the toy. Sure enough, the 12-month olds who had this self-experience no longer followed the blindfolded adult's head turn. Infants used their own experience that the cloth blocked their own view to understand their partner's experience that the blindfold blocked the other person's view (Meltzoff & Brooks, 2008). This experiment shows that what children learn about themselves can be used to understand others—an insight that will later help children develop a *theory of mind* (the understanding that other people have individual thoughts, feelings, and desires just like the children do themselves).

Infant gaze following is also a major factor in language development. Results from our research show that the better an infant is at following an adult's gaze and pointing to objects at 10 to 11 months, the bigger their vocabulary at 2 years old (Brooks & Meltzoff, 2008). Gaze following and pointing are examples of joint attention. Shared attention can help a child hone in on what an adult is talking about, providing key pieces as they assemble the language puzzle.

FIGURE 2. **Gaze following in babies**

The adult first looks at the child, then turns to look at one of the two identical toys. The 1-year-old watches as a researcher turns and then looks to the same object. (From Meltzoff, Kuhl, Movellan, & Sejnowksi, 2009, *Science, 325*, 284–288.)

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The more back-and-forth vocal exchanges that occur, the more opportunities for infants to learn language.

"I Can Do That, Too!"—Infant Imitation

Within an hour of birth, infants pay attention to human faces and imitate simple facial expressions (Meltzoff & Moore, 1977, 1983). The discovery of this ability changed the way researchers think about early learning and how infants register the similarity between self and other. Young children are constantly observing adults' behavior and use imitation to learn from adults even before adults can use language to teach them. Learning by watching is one of the most powerful learning tools infants use before they can talk. Imitation helps children understand, at a fundamental level, that they are similar to others, which Meltzoff (2007) has described as the "Like-Me" theory of social-cognitive development. The central idea of this theory is that young children, and even infants, are striving to build maps that connect self and other—they can recognize that others are "like-me" and they want to be "like you."

Deferred imitation, or imitation after a delay, is also a key to infant learning and a useful way to measure babies' memory. Nine-month-olds show deferred imitation of a simple action, such as pushing a button, even after a 24-hour delay (Meltzoff, 1988). They can watch an adult perform an action on an object, store it in their memory, then recall and perform the same action 1 day later. Twelve-month-olds imitate a simple action after a 4-week delay (Klein & Meltzoff, 1999). Amazingly, 16-month-olds can remember an action for 4 months (Meltzoff, 1995). Deferred imitation supports the teaching and learning of non-verbal behaviors and traditions.

Not only do children imitate across time, but they are also adept at imitation across different settings and contexts (Barnat, Klein, & Meltzoff, 1996) as well as across social situations, imitating familiar people, strangers (Hayne, Boniface, & Barr, 2000), and even other infant peers (Hanna & Meltzoff, 1993). By imitating social partners of all ages, children have more opportunities to learn about the world and to see how others are "like me."

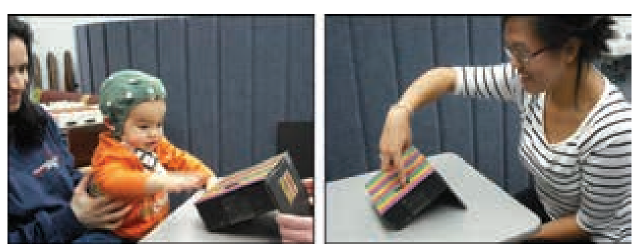
Recent advances in neuroscience allow researchers to explore the neural underpinnings of imitation. While wearing an EEG cap to measure brain activity (see Figure 1), infants watched a researcher demonstrate an action, such as pushing a button on a box. It is interesting that a specific change occurs in infants' brain activity not only when infants push the button with their own hands, but also when they simply watch the researcher push the button (Marshall & Meltzoff, 2014; see Figure 3). These are exciting new discoveries combining infant behavior and infant neuroscience: it's as though the infant brain is saying "Hey, you're like me! I can do that, too."

How the Baby's Body Is Represented in the Baby's Brain: The Power of Touch

A gentle touch is one of the earliest forms of communication between babies and their caregivers. That touch says "I love you" long before infants understand language. Touch may be one of the first ways that infants recognize the social presence of others, and research with adults suggests that the perception and sensation of a person's own body, and those of others, are deeply intertwined with that person's social and emotional interactions with the world (Damasio, 1994).

In a recent study, we explored how infants' brains process touch. Babies sat on their parent's lap while wearing an EEG cap to sense electrical activity in the brain. Infants then received a series of light touches, alternating randomly between the right and left feet and hands. Infants' brains responded with different patterns of neural activity that corresponded to the specific part on the body that was touched—hands versus feet (Saby, Meltzoff, & Marshall, 2015). At this early stage of the neuroscience work, scientists are describing these results as revealing "body maps in the infant brain" (Marshall & Meltzoff, 2015). Understanding how infants process touch, and what parts of their brains become active when different parts of their body are touched, provides a scientific foundation for understanding the origins of a self-concept.

FIGURE 3. **Scientists are uncovering the neural bases of infant imitation**



Similar brain regions seem to be involved when the infant performs a simple action, such as pushing a button, and when they observe someone else doing so. This result shows the infant social brain in action. (From Marshall & Meltzoff, 2011, *Developmental Cognitive Neuroscience, 1*, 110–123.)

Touch and a sense of one's own body are essential in infant development and mental health. In order to imitate their social partners, infants need to map the behaviors they observe onto their own bodies. Understanding how neural body maps develop, and how an infant relates her body to the bodies of her social partners, will help explain how infants learn so rapidly from watching others in their culture. Future research may allow us to illuminate how the body map originates (perhaps even prenatally) and how it is changed with experience—for example, how the hand body map is changed when infants begin to reach out and grab objects or the foot body map is changed when they begin to walk. Researchers have hypothesized that babies' body maps are crucial for connecting self and other and may form the foundation for empathy and social-emotional connectedness (Marshall & Meltzoff, 2015; Meltzoff, 2013).

The Puzzle of Other Minds, Cracking the Emotional Code

A child's first introduction to another person's mind is through the back-and-forth interactions they have with their caregivers. When an infant smiles or lets out a little cry, and their caregiver responds accordingly, the infant learns how people relate to each other. As their relationships becomes more nuanced, children look to adults for emotional guidance in uncertain situations. A child can look to a trusted caregiver to learn whether it's okay to approach a new person or venture into freshly fallen snow (Feinman, Roberts, Hsieh, Sawyer, & Swanson, 1992; Sorce, Emde, Campos, & Klinnert, 1985). Fourteen-month-old infants who watch an adult smile as he peeks inside one box, and then wrinkle his nose in disgust as he peeks in another, are more likely to look inside the box that appeared to make the adult happy (Repacholi, 1998). They use other people's social cues to make decisions about how to explore objects in their world. This is called *social referencing*.

Looking to others for clues extends beyond objects. Young children also watch and listen intently to emotional reactions exchanged between adults and then shape their own behavior accordingly. Scientists call this *emotional eavesdropping* (Repacholi & Meltzoff, 2007). In one study, toddlers watched an adult play with a toy that made a sound. A second adult then came in and either expressed anger (as if it were a "forbidden toy") or had a neutral response to the first adult playing with the toy. Infants who watched the adult express anger were hesitant to play with the toy (Repacholi, Meltzoff, Rowe, & Toub, 2014). These experiments are among the first to demonstrate that infants modify their own behavior in response to emotional exchanges that they are not directly a part of. They learn by "eavesdropping" on the emotional interchanges that they see and hear between two other people. By observing the emotional responses of other people in their lives, infants learn important lessons about how people respond to actions, what are "forbidden actions" in this family or culture, and even about the personalities of the people around them. This ability is crucial for success in school and in the personal relationships people maintain throughout their lives.

A gentle touch is a form of nonverbal communication between babies and their caregivers.

Building the School-Ready Brain

Years of research have shown that the secret to building a school-ready brain is really no secret at all. Children are born learning, and the rich social interactions they have in their early years are important. Engaging with children from an early age and encouraging back-and-forth volleys of communication have measurable benefits for later development. We found that the ability of 6-month-old infants to tell the difference between the basic components of speech sounds predicts their later language abilities (Tsao, Liu & Kuhl, 2004). Using parentese also helps infants process language because it stretches vowel sounds. The more infant-directed speech an infant hears, the larger their vocabulary is likely to be at 2 years old (Ramírez-Esparza et al., 2014). Other components of social interactions, such as eye-gaze,

Learn More

Scientist in the Crib
A. Gopnik, A. N. Meltzoff, & P. K. Kuhl (2000)
New York, NY: Harper Collins

The latest science shows that babies and young children know and learn more about the world than adults could have imagined. They think, draw conclusions, make predictions, look for explanations, and even do experiments. Adults can learn as much by looking in the crib and the nursery as by looking in the scientist's petri dish or the telescope. In some ways, we learn more—we learn what it means to be human.

I-LABS Online Modules
www.ilabs.uw.edu/outreach-modules

I-LABS is building an online library of resources for early learning professionals, parents, caregivers, policymakers, and interested community members. The online training modules are designed to share the latest science of child development with the broader community. Each module explores a particular topic, such as early brain development, children's imitation, or language acquisition, and nests it within the larger landscape of child development. All modules are free and are designed to be useful for both everyday interactions with children and for informing systems-level programs and policies.

are also correlated with increased language learning outcomes (Conboy, Brooks, Meltzoff, & Kuhl, 2015; Brooks & Meltzoff, 2008). Further, infants who are better at gaze-following before their first birthday have been found to use more words to describe mental states at 2½ years old, and in turn, children with higher mental-state vocabulary at 2½ years have better theory of mind scores at 4½ years old (Brooks & Meltzoff, 2015). This link between skills in the first year to abilities in preschool helps to connect the dots between infancy and school readiness.

Preparing a child for school means preparing them socially, emotionally, mentally, and linguistically—it means getting them ready for non-academic as well as academic challenges. A school-ready child is one who has been exposed to rich social interactions and has been welcomed into conversations from the earliest phases of life. The playful back and forth between an infant and her father provides exquisite opportunities for early learning. Embracing these everyday moments, filling them with language, social imitation, and gentle touches transforms these interactions into learning moments. There is a growing appreciation of how the infant social brain is biologically prepared for interaction, and how interpersonal exchanges in turn influence brain development (Meltzoff et al., 2009). Babies are born learning, and the people in their social environment feed their hunger to learn.

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Andrew N. Meltzoff, PhD, holds the Job and Gertrud Tamaki Endowed Chair and is the co-director of the University of Washington Institute for Learning & Brain Sciences. A graduate of Harvard University, with a doctorate from Oxford University, he is an internationally renowned expert on infant and child development. His discoveries about infant imitation have contributed to the understanding of early cognition, personality, and brain development. His research on social-emotional development and children's understanding of other people has helped shape policy and practice.

Patricia K. Kuhl, PhD, is the Bezos Family Foundation Endowed Chair for Early Childhood Learning and co-director of the University of Washington Institute for Learning & Brain Sciences. She pioneered research on EEG and MEG methods for early language development and has published influential studies showing how young children do (and don't) learn from TV. Dr. Kuhl's work has played a major role in demonstrating how early exposure to language alters the brain. This has implications for critical periods in development, for bilingual education, reading readiness, developmental disabilities, and for computer speech recognition.

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