

Chapter 2. Neuroscience and education: How early brain development affects school

By

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Research on young children reveals their extraordinary ability to learn. Early learning prepares children to succeed in school and is a key factor in enhancing education worldwide. Regarding language and literacy, high quantity and quality of language addressed to young children, and parents' use of the speaking style called "parentese", are associated with advanced early language skills and reading readiness in children at the age of 5 years. Brain imaging on young infants demonstrates the importance of social interaction for the growth of language. Translational science on "parent coaching" for children's language skills resulted in significant increases in both parental language to infants and language skills in children. A method and curriculum created for teachers to enhance early bilingual language learning ignited dual-language learning in infants aged 7 months to 3 years with 1-hour per day of instruction. Scientific studies of children's minds and brains can positively affect education policy.

One of the transformative areas of discovery of the science of learning centres focused on the developing mind and brain of the child. Children’s extraordinary learning during the period from birth to five years of age was shown to be far greater than scientists and educators previously thought. During this early period, scientists have shown that brain growth and behavioural advancements in learning can be directly linked to a child’s opportunities to learn, and that reduced opportunities to learn can contribute to a lack of “preparation” for formal schooling. The “preparation gap” has been linked in numerous studies to a failure to succeed in school and in life.

The science of early childhood has shown not only that our youngest citizens learn more and learn earlier than previously thought, but also how they learn, and why they do or do not learn. These discoveries have produced a grand challenge for educators and policymakers, not only in the United States but all over the world as governments begin to understand the value of investing in young children’s natural abilities to learn. Governments worldwide are now seeking science-based information about how children learn with the intention of using that information to affect policy.

The goal of this chapter is to briefly share some of the exciting basic science discoveries on early learning and brain development and to describe successful interventions that show promise for scalability in early education centres and with parents who want to understand how to best support their children’s learning.

Integral to these discoveries is the work on the developing brain. My laboratory pioneered brain measures that are safe and non-invasive for use with young children. Our approach was to develop methods that allowed us to use sophisticated and safe brain imaging equipment (magnetoencephalography or MEG, see Figure 2.1) to record, for the first time, brain activity as infants listen to words or music, look at people or objects, or experience tactile stimulation. MEG analysis produces a movie that shows the baby brain at work and is helping us uncover the mechanisms underlying learning that can only be revealed by brain imaging infants as they engage in a task.

The discoveries discussed here use early language learning as a model system. Language learning provides an example in which brain imaging and behavioural studies reveal the impact of experience on learning and explore the brain mechanisms underlying young children’s extraordinary neuroplasticity – the ability of the brain to change with experience. Language learning thus provides a window into the young child’s brain. Basic science discoveries have elucidated how language learning works, what it requires, and guided us towards language interventions – with parents and in schools – that successfully improve children’s language learning outcomes.

Figure 2.1. An 11-month-old infant being tested in the MEG machine

Source: Ferjan Ramírez, N. et al. (2017^[1]), “Speech discrimination in 11-month-old bilingual and monolingual infants: A magnetoencephalography study”, *Developmental Science*, Vol. 20/1, p. e12427, <http://dx.doi.org/10.1111/desc.12427>.

Basic science: Infants are linguistic geniuses

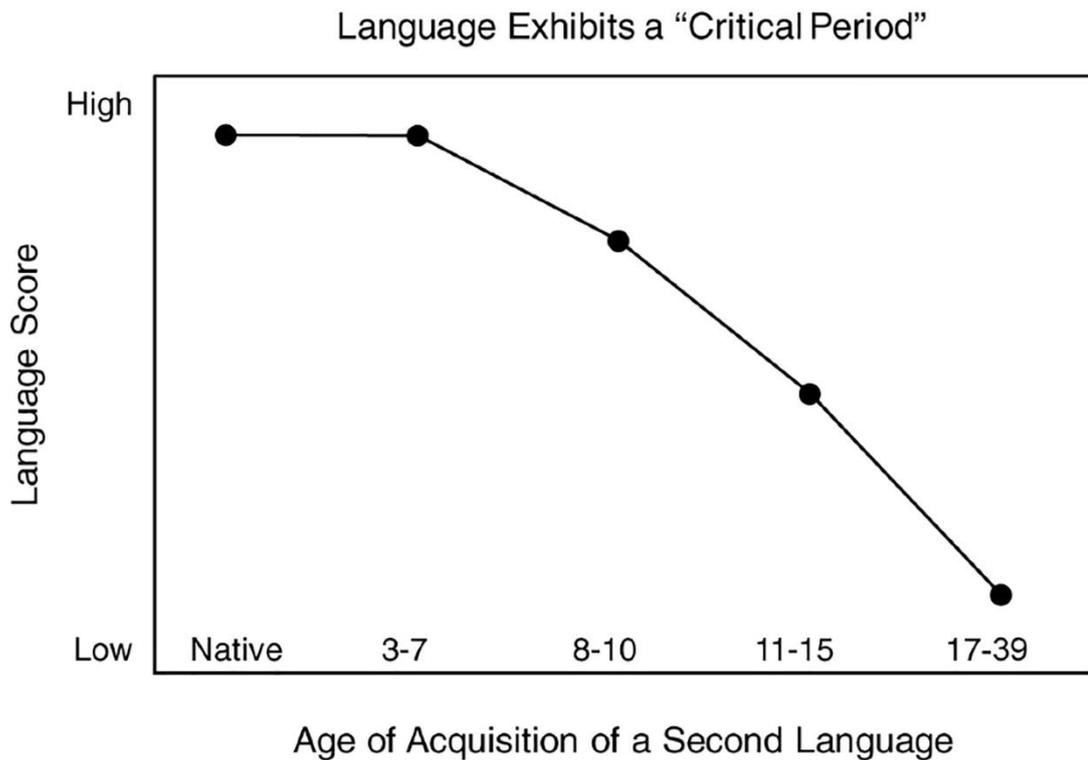
Infants begin life with brain systems that allow them to acquire any and all languages to which they are exposed. A stage-setting concept for human language learning is the graph shown in Figure 2.2 (Kuhl, 2011^[2]). The graph shows a simplified schematic of second language learning as a function of age. It shows that infants and young children are superior learners when compared to adults, in spite of adults’ cognitive superiority. Language is one of the classic examples of a “sensitive” period in neurobiology (Kuhl, 2017^[3]). A sensitive period marks a time in development when experience easily alters brain development. It is a very important time for building the brain’s foundation for strong language and literacy skills.

The earliest sensitive period for language learning happens during the first year of life. Between 6- and 12-months of age, infants learn the sounds that will be used to create words in their language. Each language uses about 40 phonetic units (consonants and vowels) to distinguish words, and the child’s job is to discover the set of elemental units upon which words in their culture depend and do this before their first birthdays when initial word learning begins. Studies in my laboratory demonstrate that until about six months of age, infants from all nations are able to discern differences among the sound units that distinguish words in all of the world’s languages. This “universal” ability is extraordinary,

given that the infants' parents can only discriminate the sounds contained in languages they were exposed to as a child.

By 12 months of age infants' skills narrow – the ability to discern sound differences for languages the infant has no exposure to declines sharply during the period from 6- to 12-months, while their abilities to hear differences among native language sounds improves significantly (Kuhl et al., 2006^[4]). The ability to learn during this sensitive window of opportunity predicts the speed at which a child's language will grow to the age of three (Kuhl et al., 2008^[5]), and their reading readiness at the age of five. In other words, this initial stage of language learning is very important – it establishes the foundation for language learning and literacy.

Figure 2.2. The relationship between age of acquisition of a second language and language skill



Source: Kuhl, P. et al. (2008^[5]), “Phonetic learning as a pathway to language: New data and native language magnet theory expanded (NLM-e)”, *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, Vol. 363/1493, pp. 979-1000, <http://dx.doi.org/10.1098/rstb.2007>.

Basic science: How infants learn language

What causes the transition from a “universal citizen of the world” to a “language-bound” listener? We found that two factors hold the key to infant learning during the sensitive period for language: one factor is computational and the other social. From a computational standpoint, an implicit form of learning referred to as “statistical learning” (Saffran, Aslin and Newport, 1996^[6]) plays an important role in infants' phonetic learning. During the first year of life infants are highly sensitive to the frequency with which they hear speech sounds – the distribution of the sound types they hear matters. Infants focus on the sounds that

occur with very high frequency. Languages such as English and Japanese, for example, differ in the sounds they contain and the sounds' distributional characteristics, and infants are sensitive to these distributional cues.

However, our studies further demonstrated that human infants' statistical learning skills require a social context. The impact of the social brain was shown in a study with infants at nine months of age, during the sensitive period for early phonetic learning. Infants experienced a foreign language for the first time (Kuhl, Tsao and Liu, 2003^[7]), either from: 1) a live tutor; 2) a video; or 3) audio-only presentations. In all conditions, American infants listened to four different native speakers of Mandarin Chinese during 12 sessions scheduled over 4-5 weeks. The foreign language "tutors" read books and played with toys in sessions that were unscripted. A fourth group, our controls, also experienced 12 language sessions but heard only English from native English speakers. Infants in all four groups were subsequently tested with Mandarin Chinese sounds that do not occur in English using both behavioural and brain measures of learning.

The results indicated that infants learned only from the "live-person" sessions. Infants who heard the new language from live speakers performed as well on the Mandarin sounds as the infants in Taiwan who had been listening to these sounds for ten months. Infants exposed via video or audio-only performed at chance, just like the control group who heard only English. Using the same experimental design, we extended our studies to Spanish. These new studies demonstrated that infants not only learn Spanish sounds through social exposure (Conboy and Kuhl, 2011^[8]) but also a set of Spanish words that were used during the language-exposure sessions (Conboy and Kuhl, 2010^[9]). Moreover, our Spanish experiments demonstrated that infants' social behaviours – their eye-gaze shifts from the tutor's face to the objects the tutor held while naming them in the foreign language – predicted the degree to which infants learned both Spanish sounds and Spanish words (Conboy et al., 2015^[10]).

These results were surprising. Scientists had underestimated the power and necessity of social interaction for learning. The study's result was reported widely by the press and it raised issues that are increasingly debated today about humans' need for a social context during the early period. In a world in which technology is ever present in adults' lives, and one in which even very young children are seen using smart phones and iPads, our finding raises issues about children's learning from technology. These and other findings led paediatricians in the United States to recommend that until two years of age, parents should not rely on screen technology for learning. The finding led us to argue that social interaction "gates" early language learning, that it is essential for infants to interact socially with people to learn (Kuhl, 2007^[11]).

Basic science: Language input

Classic studies by Hart and Risley in the 1990s (Mabry, 1997^[12]) in the United States demonstrated vast differences in the number of words children heard at home depending on whether they were growing up in families whose parents were on welfare as opposed to growing up in families whose parents were professionals. By age three, these data showed a 30-million-word gap for welfare children compared to children with professional parents. Brain (Raizada et al., 2008^[13]) and behavioural (Fernald, Marchman and Weisleder, 2013^[14]; Hirsh-Pasek et al., 2015^[15]) studies confirm a pattern of association between brain function in five-year-old children and the socio-economic status (SES) of the child's family – when IQ, current cognitive skills and current language skills are measured in five-year-olds, the family's SES was the most powerful variable explaining differences in brain

function in five-year-olds. Children need opportunities to learn in the early years of life for their brains to reach their full potential.

Human social interaction and language input from parents – talking and reading to children at an early age – are clearly important factors for successful language learning. But how much language do infants need to learn effectively, and does it matter how you talk to infants? My laboratory's studies have recently focused on the quality of language input. We have found that parents' use of the special speech register known as "parentese" predicts advanced future language development in children, regardless of SES. Parentese, which has a higher overall pitch, exaggerated pitch contours, a slower tempo and acoustically clearer phonetic units – is associated with advanced future language abilities in both monolingual (Ramírez-Esparza, García-Sierra and Kuhl, 2014^[16]) and bilingual infants (Ramírez-Esparza, García-Sierra and Kuhl, 2017^[17]). Parentese increases children's attention, engages them and exaggerates the acoustic differences between sounds (Kuhl et al., 1997^[18]). Our brain studies show that when young infants hear speech we see brain activity not only in the auditory areas of the brain but also in the brain centres that are responsible for children's ability to respond to us verbally. Even before infants can speak, hearing adults talk to them prompts their motor brain centres to rehearse the motor movements necessary to allow them to join the social exchange (Kuhl et al., 2014^[19]).

In the parentese studies, we recorded infants at home using small and highly accurate microphones made by LENA (LENA Research Foundation, 2015^[20]) that infants wore in light-weight vests as they went about their daily lives. We analysed the number of words infants heard and measured "turn-taking" events when parents and children exhibit back and forth language interactions. The prevalence of "parentese" versus "standard" speech was also measured. In infants recorded at 11- and 14- months of age, the prevalence of parentese in the home predicted the number of words they had mastered by two years of age. Infants who heard the most parentese each day learned over twice as many words as those who heard standard speech most of the time.

Science of the bilingual brain

Parents and teachers in the United States often believe that bilingualism puts children at risk for academic failure, confusion or language delay, but the research does not support this belief (Ferjan Ramírez and Kuhl, 2017^[21]; Hoff et al., 2012^[22]). Instead, our MEG brain studies have shown that when infants are exposed to two languages, the infant brain is just as capable of learning two languages as it is of learning one. In fact, bilingual children's productive vocabulary skills, when combined across both languages, is equal to or exceeds that of their monolingual peers (Ferjan Ramírez et al., 2017^[1]; Hoff et al., 2012^[22]). Our MEG research and behavioural studies reveal that bilingual Spanish-English infants' brain responses are just as strong in response to English as those of monolingual children exposed only to English, and the bilingual infants' brains also respond to Spanish. In other words, there is no evidence that exposure to two languages is harmful to infants' development of either the primary language or the second language. Moreover, there are demonstrated cognitive benefits of bilingualism that include enhancements in executive functions and cognitive flexibility (Bialystok, Craik and Luk, 2012^[23]).

With roughly two thirds of the world's population estimated to understand or speak at least two languages, bilingualism has become the norm in many parts of the world. In the United States, the rate of bilingualism is lower than the world's average. Nevertheless, census data indicate that 27% of US children under the age of six come from families where languages other than English are spoken, (Capps et al., 2004^[24]) and this number is projected to grow

as a result of continued migration and births to immigrant parents. Data indicate that US children who are simultaneously learning two languages (typically referred to as Dual Language Learners, DLLs) often lag behind their monolingual English-speaking peers in academic achievement and also lack a strong foundation in either language due to the low quantity and quality of input in both languages. In 2016, the White House released a policy statement (DHSS, 2016_[25]) noting a substantial mismatch between the learning experiences that DLL children need to reach their full potential, and the quality of experiences that they are currently receiving.

Interventions that utilise evidence-based practices to enhance early language learning

My laboratory has developed two language interventions that have been shown to be successful in randomised control trials. One focuses on parent “coaching” to increase parents’ use of speaking styles and social exchanges that foster language, and the other is a programme that is successful in creating bilingual infants in early education centres in only one hour per day. These two interventions have the potential to be scaled-up worldwide.

Intervention Science: Parent “Coaching” to Enhance Language Learning

It is not a given that one can “coach” parents to change their behaviour and that this will in turn improve children’s developing language skills. To test this idea, we conducted an intervention that involved coaching parents by providing them with information about brain development, language learning and their language input to their children (Ferjan Ramírez et al., 2018_[26]). Infants wore LENA recorders over two weekend days at home when they were 6-, 10- and 14-months of age. After the data from the recordings were analysed, we met with parents and shared information and data from their recordings. We discussed the power of the infant brain and the need for parents to talk and read to their children to give them ample opportunities to learn. Data shared with parents included measures of their own language input quantity and quality (parentese) when speaking to their children and were compared to the average data from comparable parents with children of the same age. Parents from a wide range of SES families were involved and they were randomly assigned to either the parent coaching group or a parent control group whose children were recorded in the same way at home but whose parents were not coached.

Parent coaching was very effective. By 14 months of age, parents who were coached showed significant increases in both the quantity and quality of language input and had children who produced significantly more language than comparable parents and children in the control group. Moreover, at 14 months of age our data show that children’s language outcomes are significantly higher in the parent-coached versus control children. No differences with the SES of the family were observed. Apparently, when given relevant information about what they can do to enhance their children’s language abilities, parents act on that information. They respond by increasing the language-input factors known to be associated with improved language outcomes, and their children’s language skills improve. We are now continuing the study to examine the longevity of the effects in parents and children. We also plan to create software that would provide all parents with these tools to improve language outcomes in their children.

Intervention science: Creating bilingual children during the sensitive period

The documented advantages of bilingualism have dramatically increased the demand for bilingual education around the world. Given that research shows that the infant brain is much more adept at learning multiple languages than the adult brain, the demand for bilingual learning programmes for young children is especially strong. In the United States, the growing need to serve DLL children has led to increased interest in evidenced-based methods of teaching, and proven curricula. Research shows that, for infants and young children, social interaction is critical for language learning, and therefore technology is not a viable approach for teaching a second language to this age group. Private schools teaching second languages to infants and young children are very expensive and thus out of reach for many families, and public educational settings lack the resources and curricula to teach second languages to young children as part of their educational experience.

Based on our 30-year history of brain and behavioural laboratory research, we asked ourselves a simple question: If we designed a curriculum and method of teaching based on our research on early language learning, could we successfully teach a foreign language in early educational settings and create truly bilingual minds? Could we ignite foreign language learning in infancy? We designed an intervention called SparkLing™ and conducted a randomised control study in four Bilingual Infant Education Centres in Madrid, Spain (Ferjan Ramírez and Kuhl, 2017^[27]) involving over 300 children ranging in age from 7-33.5 months. Children were assigned to Intervention vs. Control groups; Intervention children received 18 weeks of daily one-hour English play-based instruction, using a specially designed evidence-based method and curriculum, while Control infants in the same schools received Madrid's standard method of bilingual instruction. The four Infant Education Centres were neighbourhood schools, and these neighbourhoods differed in SES. Two of the schools served low-income neighbourhoods, and two served middle-income neighbourhoods.

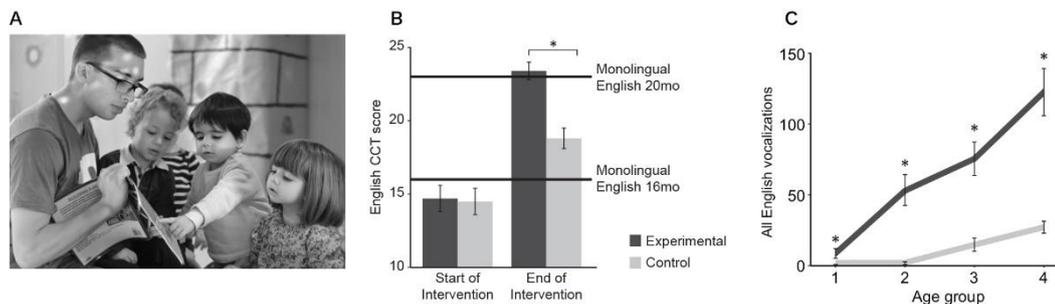
Intervention sessions followed six SparkLing™ principles, each backed by research results: 1) The learning context was highly social and interactive; 2) tutors used a high quantity of English speech in the classroom and all language input to children used “parentese” speech; 3) tutors were native speakers of English; 4) children heard English from multiple talkers; 5) children were encouraged to talk, even if babies were only babbling, and interact from the first session; and 6) the curriculum was play based, with activities adapted for age and children's language levels (Figure 2.3A). Control children participated in the Community of Madrid's standard bilingual programme, which consisted of approximately two hours of weekly instruction through typical nursery school activities such as book reading, nursery rhymes and singing.

Our results demonstrated clear and significant effects of the Intervention at each of the four Early Education Centres in Madrid, for the whole age range tested. We used standardised measures of English and Spanish comprehension at the beginning and end of the Intervention to document learning. We also measured English production, recording infants using LENA recorders. Importantly, the results did not differ by the social-economic status of the neighbourhoods. At the beginning of the 18-week Intervention period (Figure 2.3B), comprehension of English and Spanish was equivalent in Intervention and Control children. At the end of the 18-week period, Intervention children were significantly better at English comprehension than Controls, who also showed gains. Spanish comprehension showed equivalent and significant gains in both Intervention and Control children, as expected, over the 18-week period. English speech production was measured in Intervention children every two weeks, and in Control children at the end of the 18-week period (Figure 2.3).

Intervention children produced significantly more English vocalisations at each age when compared to Controls. Our results suggest that all infants, regardless of socio-economic background, are capable of acquiring a second language through high quality playful social interactions (Ferjan Ramírez and Kuhl, 2017_[27]).

Figure 2.3. Randomised control Language Intervention in Madrid Bilingual Infant Education Centres

A: English session at one of the participating schools. B: English CCT scores at the start and at the end of Intervention, for Intervention (black) and Control (grey) participants. C: English vocalisations per child per hour at the end of the 18-week period, for the Intervention (black) and Control (grey) children by age group. Age groups (in months): 1 = 7-14, 2 = 14-20.5, 3 = 20.5-27, 4 = 27-33.5.



Source: Ferjan Ramírez, N. and P. Kuhl (2017_[27]), “Bilingual baby: Foreign language intervention in Madrid’s Infant Education Centers”, *Mind, Brain, and Education*, Vol. 11/3, pp. 133-143, <http://dx.doi.org/10.1111/mbc.12144>.

Policy implications and the future success of our children

Our results have two significant broader impacts for education and society worldwide. First, investments in early childhood learning can produce profound results, a conclusion supported both by the basic laboratory research on language learning in early childhood and by the translational research we conducted with parents and in Early Education Centres in Madrid. Research can now connect the dots from early childhood to kindergarten readiness in children from all socio-economic backgrounds.

The Obama administration held a White House conference in 2014 that calculated the benefits of investing in children’s learning in the first five years of life, concluding that early investments produce large dividends. An analysis by the President’s Council of Economic Advisers described specific economic returns to investments in childhood development and early education with roughly USD 8.60 in benefits to society for every USD 1 spent. About half of this return comes from increased earnings for children when they enter the workforce (data from the Bill & Melinda Gates Foundation, as well as the data of Nobel Laureate and economist James Heckman, support this view).

The scientific findings, along with the economic arguments, suggest that governments seeking to enhance K-12 learning consider investing in children before they get to school. Young children have an enormous capacity to learn, and both brain and behavioural science reveals how an enriched environment changes the brain and supports its growth at critical times in development. In many countries around the world, governments and education ministries are discussing strategic plans that include an emphasis on early learning and preparation for school. The science of early learning, including both brain and behavioural studies, has advanced this cause.

Second, the basic science on language learning has led to two evidence-based interventions (SparkLing™ and Parent Coaching) that are effective in children aged zero to three years. Our findings underscore an important point about the human ability to acquire language: Children’s language learning is experience dependent, and early learning is potent. All children have the capacity to develop strong language skills not only in a single language but in a second language early in infancy (Kuhl, 2010_[28]). Moreover, infants and toddlers can benefit from enhanced language input in a social context both at home and in a school setting. Given the many advantages offered by excellent language skills, and the additional benefits of bilingual language skills, policymakers can affect change that supports learning in families and educational systems worldwide. Basic neuroscience showing how the human brain learns is now reaching out from basic science laboratories to affect the homes and nursery schools of the future and this holds promise in preparing all our children for success in school and in life.

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