The Impact of Minimal Language Experience on Children During Sensitive Periods of Brain and Early Language Development: Myths Debunked and New Policy Implications

Dr. Laura-Ann Petitto

Science Director & Co-Principal Investigator,
The National Science Foundation (USA) and Gallaudet University's
Science of Learning Center
Visual Language and Visual Learning, VL2;
Founder and Science Director of the Petitto Brain and Language Laboratory for Neuroimaging, BL2;
Full Professor, Department of Psychology, Gallaudet University
Washington, D.C.
USA

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Abstract

Many children around the globe suffer from "*minimal language experience,"* whereupon they have little exposure to natural language during sensitive periods of early brain and language development—a situation that can render lifelong language and reading challenges. Beyond "minimal," some children can receive *no* accessible early life language experience, as is the case for young children in neglectful contexts with little social interactions. Yet this can also be true for children in homes where adults have good intentions to promote their growth, such as deaf infants, and particularly those slated for Cochlear Implants. Here, a worldwide practice has evolved whereupon these deaf babies can receive no systematic and accessible visual sign language exposure for an extended time gap between birth and the onset of surgery and speech training beginning around 12-18 months or more. This practice has been fueled by misunderstandings and ubiquitous myths about the biological imperative that all children must be exposed to natural language in early life, the biological equivalence of signed and spoken languages in the human brain, and the human child's developmental requirements that promote optimal exposure to two or more languages ("bilingualism") and reading success. In this article, seven of the most common myths associated with the learning capacity of young children are addressed—then debunked—through evaluation of powerful scientific evidence, followed by discussion of the impact that this new scientifically based knowledge has for educational policy. While the myths are associated with deaf children, the present work lays bare the universals of language learning in all children, the optimal conditions for becoming bilingual in all children, and the multiple pathways that all children can benefit from to become a skilled and successful reader.

Minimal or insufficient language experience in very young children has been shown to have a devastating impact on the their capacity to learn language and to achieve healthy reading and literacy skills (e.g., Caskey et al., 2014; Huttenlocher et al., 1991; Nelson, 2000; Neville & Bruer, 2001; Valian, 1999). Some infants are at particular risk, as beyond minimal language experience, it is possible that they can receive *no* accessible early life language experience. This can be true for children around the globe in home environments with little early life language and social interactions. This can also be true even for children in homes where adults have the good intention to promote their growth. For example, many deaf and hard of hearing children are born to non-signing hearing parents (Mitchell & Karchmer, 2004). For those deaf infants slated for Cochlear Implants, an unfortunate worldwide practice has evolved whereby signed language can be wholly withheld in early childhood. This practice has been fueled by misunderstandings, erroneous beliefs, and ubiquitous myths about the biological imperative that all children must be exposed to natural language in early life, the biological equivalence of signed and spoken languages in the human brain, and the human child's developmental requirements that promote optimal bilingualism and reading success. In this article, seven of the most common myths associated with the learning capacity of young children are addressed—then debunked—through evaluation of powerful scientific evidence, followed by discussion of the impact that this new scientifically based knowledge has for educational policy. While the myths are associated with deaf children, the present work lays bare the universals of language learning in all children, the optimal conditions for becoming bilingual in all children, and the multiple pathways that all children can benefit from to become a skilled and successful reader.

To foreshadow the science to come, the seven myths explored here are as follows:

Myth 1. Speech and sound are absolutely necessary to achieve normal language acquisition. Exposure to anything but spoken language in early life—for example, early exposure to a signed language—fundamentally harms normal spoken language acquisition. Speech and sound should be learned first in early *life, and it is fine to learn signed languages later, as it does not matter when signed languages are learned.*

Myth 2. Speech and sound are absolutely necessary to become a healthy and successful reader.

Myth 3. Speech is biologically superior to sign. The parts of the brain that process spoken languages are "privileged" sound and spoken language processing neural sites and systems that are different from those parts of the brain that process signed languages.

Myth 4. Early bilingual language exposure causes language delay and language confusion. It is best to stabilize children first in one language (often called the "mother tongue"), followed by the other. Similarly, for deaf children, it is best to expose the child to a spoken language first, and then when it is "safe," permit exposure to a signed language, if absolutely necessary.

Myth 5. To be a good reader, students with bilingual language knowledge must practice harder at only the majority *language skills (for example, drilling and practice in only spoken English, writing English, and reading English in students who also use another language, such as a natural signed language).*

Myth 6. Early signed language exposure "colonizes" the part of the brain needed to process speech and sound, damaging a deaf child's chances of learning spoken English.

Myth 7. The brains of deaf children are disabled at birth. Development of these children is best viewed as growth of a disabled child.

The body of scientific research used to debunk the seven myths draws from converging evidence emerging from the past ten years of scientific discovery by researchers in the USA's National Science Foundation and Gallaudet University's Science of Learning Center, called "Visual Language and Visual Learning (VL2)," with major contributions arising from its affiliated "Petitto Brain and Language Laboratory for Neuroimaging (BL2)." The research evidence also includes scientific discovery from around the world. Added to the high scientific standards and outcomes required of the USA's National Science Foundation, our VL2 Science of Learning Center also created the first PhD in Educational Neuroscience program in the USA, drawing from our earlier founding and advance of this exciting discipline (Petitto & Dunbar, 2004). While Cognitive Neuroscience involves studies of learning and higher cognition across the lifespan, its sister discipline, called Educational Neuroscience, includes Cognitive Neuroscience and behavioral studies of five core domains crucial to early childhood learning (language and bilingualism, reading and literacy, math and numeracy, science and critical thinking/higher cognition, and social and emotional cognition). Even more, Educational Neuroscientists are committed to building meaningful and principled ways that science can be translated for the benefit of education and society today. The present article strives to be an example of this! Together, the body of scientific evidence described below provides first-time answers to looming questions about how best to promote healthy child cognitive development, early language learning, bilingualism, and early reading, which have powerful implications for educational policy at the local, national, and international levels.

Myth 1: *Speech and sound are absolutely necessary to achieve normal language acquisition. Exposure to anything but spoken language in early life—for example, early exposure to a signed language—fundamentally harms normal spoken language acquisition. Speech and sound should be learned first in early life, and it is fine to learn signed languages later, because it does not matter when signed languages are learned.*

Lessons Learned from Science: Speech and sound are *not* necessary for normal language acquisition. Children with early exposure to signed languages achieve the same normal language acquisition milestones, exhibiting the identical "sensitive periods" for language learning and on the identical time table, as seen in children acquiring spoken languages—a dramatic demonstration that human language learning is not tied to speech or sound. Early exposure to a signed language yields *facilitation*—rather than harm—to the child's ability to learn a spoken language. Learning a signed language very early in life can help the child's acquisition of spoken language. There are two scientific reasons for this. First, early exposure to an accessible language and its systematic patterning “wedges open” and keeps “alive” the brain’s processing sites that are biologically tuned to detecting highly specific rhythmic temporal (phonetic-syllabic) patterning within natural language during the precise early sensitive periods when the infant needs to encounter these language patterns most. For the human brain, exposure to an accessible natural language and its systematic patterning must occur in very early life, be it language on the tongue (spoken languages) or language on the hands (signed languages). Late exposure to human language—especially late exposure to an accessible first language (which, in turn, causes the baby to miss key “sensitive periods” in brain and language development)—is biologically non-optimal and causes a cascade of devastating higher cognitive, language, and reading deficits that can span life. Second, young children acquiring a signed language are typically also learning a spoken language in a manner similar to early bilingual language learning situations. This is optimal. Here, each language strengthens the other. Sign + speech exposed children demonstrate the identical bilingual language learning and reading, as well as bilingual processing *advantages,* discovered in bilingual children learning two or more spoken languages. It *does* matter when signed languages are learned. The brain research shows that, like speech, signed languages must be introduced very early in life just like any spoken language. Research has further shown that signed and spoken languages are best learned in very early life within the identical developmental period, preferably through bilingual language learning.

Scientific Evidence: All hearing children acquire language on a strikingly regular developmental timetable, revealing the same universal language acquisition milestones: babbling around 6 months, first words around 12 months, first two-word combinations around18 months, etc. This was thought to be driven by the development of the human speech production mechanisms (talking) and the capacity to hear. Yet children with early exposure to signed languages also achieve every one of these universal milestones in language acquisition and on the identical developmental timetable. This includes babbling around 6 months, and all other language acquisition milestones — yet here it involves silent signed languages on their hands (cf. Petitto and Marenette, 1991; Baker, Golinkoff & Petitto, 2006; Petitto, 2009; Petitto, 2000; Petitto, 1989a; Petitto, 1989b; Petitto, 1987; Petitto, Holowka, Sergio, & Ostry, 2001; Petitto, Holowka, Sergio, Levy, & Ostry, 2004).

Studies of early sign-exposed deaf children show that exposure to a visual language actually *facilitates* the acquisition of spoken language. How can this be biologically so? First, early exposure to an *accessible* language and its systematic patterning (such as a visual signed language) "wedges open" and keeps "alive" the brain's processing sites that are biologically tuned to detecting highly specific rhythmic temporal (phonetic-syllabic) patterning within natural language during the precise early sensitive periods when the infant needs to encounter these language patterns most (Petitto, Langdon, Petitto, Langdon, Cochran, Andriola, Stone, & Kartheiser, 2016; see also Petitto, Berens, Kovelman, Dubins, Jasińska & Shalinksy, 2012).

Second, the classic patterns observed in *bilingual language learning and reading* are present even in the acquisition of a signed and a spoken language (Allen, 2015a; Allen, Letteri, Choi, & Dang, 2014; Holowka, Brosseau-Lapre, & Petitto, 2002; Kargin, Guldenoglu, Miller, Hauser, Rathmann, Kubus, & Superegon, 2012; Koo, Crain, LaSasso, & Eden, 2008; McQuarrie & Abbott, 2013; Conference presentation McQuarrie & Enns, 2015; McQuarrie & Parrila, 2014; Miller, & Clark, 2011; Petitto, Katerelos, Levy, Gauna, Tétrault, & Ferraro, 2001; Petitto & Kovelman, 2003; Stone, Kartheiser, Hauser, Petitto, & Allen, 2015; VL2 published Research Brief No. 2: Baker, S., 2011, "Advantages of Early Visual Language").

Moreover, early-sign exposed deaf adults and children show similar *bilingual language processing advantages* in their signed and spoken languages as is seen in hearing bilinguals processing their two spoken languages (*Bilingual adults, one signed and one spoken language:* Bélanger, Mayberry, & Rayner, 2013; Clark, Gilbert, & Anderson, 2011; Corina, Lawyer, Hauser, & Hirshorn, 2013; Dye & Hauser, 2014; Kovelman, Shalinsky, Berens, & Petitto, 2014; Kovelman, Shalinsky, White, Schmitt, Berens, Paymer, & Petitto, 2009; Morford & Carlson, 2011; Morford, Kroll, Piñar, & Wilkinson, 2014; Morford, Wilkinson, Villock, Piñar, & Kroll, 2011; Piñar, Dussias, & Morford, 2011; Traxler, Corina, Morford, Hafer, & Hoversten, 2013. *Bilingual adults, two spoken languages:* Kovelman, Baker, & Petitto, 2008b; Kovelman, Shalinsky, Berens, & Petitto, 2008. *Bilingual children, one signed and one spoken language:* Petitto, 2009; Petitto, 2000; Petitto, Holowka, Sergio, & Ostry, 2001; Petitto, Holowka, Sergio, Levy, & Ostry, 2004; Conference presentation Petitto, Langdon, & Stone, 2015; *Bilingual children, two spoken languages*: Jasińska & Petitto, 2013; Jasińska & Petitto, 2014; Kovelman, Baker, & Petitto, 2008a; Kovelman, Berens, & Petitto, 2013; Kovelman, Salah-Ud-Din, Berens, & Petitto, 2015).

Policy Implications: All human language is acquired through the brain's sensitivity to specific patterns at the heart of language, be it patterns on the hands in signed languages or patterns on the tongue in spoken languages. Language patterns are key to the brain — not sound. This is universal. Early sign exposure does not harm a child's chances of learning a spoken language; it helps. A child who is exposed to sign language and a spoken language is bilingual. Early bilingual language exposure strengthens the brain's processing of each language, with early bilingual language exposure being utterly optimal in human development. A bilingual Sign Language-Spoken Language learning model is vital to young deaf children's normal language acquisition and academic success (for example, the bilingual ASL-English model used in some schools in the United States, and the BSL-English model used in some schools in the United Kingdom, and other such bilingual signed + spoken language programs). The belief that learning sign language should wait until the child is older is wrong. It is a most damaging myth that flies in the face of all contemporary biological knowledge about children's optimal language learning and higher cognitive development and the sensitive periods within which children learn language most optimally. Late exposure to any language—and especially late exposure to a signed language—introduces the risk that the deaf child will miss the critical language development period and, importantly, the benefits that come from early bilingual language learning.

MYTH 2: *Speech and sound are absolutely necessary to become a healthy and successful reader.*

Lessons Learned from Science: Speech and sound (or some access to sound) are *not* necessary to become a successful reader. Studies of hearing children have found that they use multiple pathways to successful reading. Studies of skilled deaf readers have found that they also develop multiple pathways to successful reading. This includes the use of silent, visual sign phonological units (homologous to sound phonological units), both to segment and to discern the patterning of the segments, en route to decoding meaning from print. In turn, our use of visual sign phonological units when teaching children to read can have revolutionary and transformative impact on reading success in young deaf children around the world.

Scientific Evidence: That natural signed languages possess the identical level of language organization known as "phonology" has been understood for decades (see pioneering work by Brentari reviewed in Brentari, 2011; this is also true of other levels of language organization, such as syntax, morphology, and semantics). Similarly, in both signed and spoken languages, skilled early readers engage in "phonological" decoding to discover meaning from print. For the hearing child the mapping is from sound segments to print, and for the deaf child the mapping is from silent, sign-based phonological representations to print. To the human brain, it is the *mapping from segments to print* that is utterly key—not whether the segment is made up of a sound unit or a visual unit (for a detailed review see especially, Petitto et al., 2016; for research evidence see, e.g., Allen, 2015a; Allen, 2015b; Allen & Enns, 2013; Conference presentation Allen & Morere, 2016; McQuarrie & Abbott, 2013; McQuarrie & Parrila, 2014; Petitto et al., 2016; VL2 published Research Brief No. 4: Morere, D., 2011, "Reading Research and Deaf Children").

With early sign language exposure, a deaf or hearing emergent reader builds an identical abstract level of language organization —for signed language, called "Visual Sign Phonology" — from the rhythmic-temporal patterned visual sequences that they see around them, including patterns of sign phonetic and sign syllabic units, and fingerspelling, and may include patterned mouth units (Allen, 2015a; Allen, Letteri, Choi, & Dang, 2014; Conference presentation Allen & Morere, 2016; Baker, Golinkoff, & Petitto, 2006; Baker, Idsardi, Golinkoff, & Petitto, 2005; Krentz & Corina, in press; Liu, Liu, & Andrews, 2014a, 2014b; Conference presentation McQuarrie & Enns, 2015; McQuarrie & Parrila, 2014; Morford, Staley, & Burns, 2010; Conference presentation Petitto, Langdon, & Stone, 2015; Petitto & Marentette, 1991; Rathmann, Mann, & Morgan, 2007; Schick & Gale, 1995; Schwartz, Schick, Whitney, & Coady, 2011). Like a hearing child who builds a sound phonology from the bits of sound segments and their systematic patterning around them (sound-phonetic and sound-syllabic units), the deaf emergent reader builds an identical abstract level of language organization from the bits of visual signed language segments and the patterning around them (sign-phonetic and sign-syllabic units in Visual Sign Phonology; Petitto, 2007; Petitto, 2005; Petitto, Holowaka, Sergio, & Ostry, 2001; Petitto, Holowka, Sergio, Levy, & Ostry, 2004; Conference presentation Petitto, Langdon, & Stone, 2015). This critical information enables these deaf children powerful abilities to segment the constantly varying linguistic stream around them, to categorize these segments, to tacitly discern their statistical patterning regularities and, crucially, to use this segmentation capacity to decode text on the printed page en route to meaning just like hearing children exposed to speech.

Crucially, deaf children who are taught these building blocks of sign-phonetic and sign-syllabic organization (inclusive of fingerspelling) in classroom training paradigms demonstrate *reading advantages* over deaf children who are receiving traditional language drilling exclusively in spoken language. Notably, this even includes reading advantages (resulting from sign-phonetic/syllabic training paradigms) in children with Cochlear Implants or hearing aids who had been previously receiving exclusive speech training (Conference presentation Jasińska, Langdon, & Petitto, 2013; Stone, Kartheiser, Hauser, Petitto, & Allen, 2015).

Policy Implications: Speech and sound are *not* necessary for successful reading. For decades young deaf children have been assumed to be locked in reading failure because they do not have access to sound. Recognizing that silent Visual Sign Phonology can support, even enhance, development of children's reading skills can have a revolutionary impact around the world. Sign-phonemic awareness and fingerspelling segmentation can be incorporated into classroom strategies to catapult all children's reading success, be they deaf or hearing, and involving all languages, be they with alphabetic or non-alphabetic/logographic writing systems (such as Chinese). For example, deaf children with strong American Sign Language (ASL) phonemic awareness have better reading skills in English. Fingerspelling is another important sign-phonological unit for these young deaf readers. Teachers who understand the value of silent visual sign-phonological segmentation, as well as fingerspelling segmentation and its systematic patterning regularities, can incorporate sign phonemic awareness and fingerspelling into classroom strategies to catapult reading success in their nation's deaf children. A young reader's ability to draw upon silent sign-based phonology is also very helpful when children learn to read in languages that do not always have direct "letter-to-sound" correspondences.

MYTH 3: *Speech is biologically superior to sign. The parts of the brain that process spoken languages are "privileged" sound and spoken language processing neural sites and systems that are different from those parts of the brain that process signed languages.*

Lessons Learned from Science: To the human brain, no one language is superior over the other. All human languages share overlapping neural parts and systems, patterns of language acquisition, and natural language processing despite vast surface differences in surface language typology (grammatical structures and functions), modality (signed or spoken) or general diversity among the world's languages. The parts and neural systems of the brain that process spoken languages are largely the *same* as the parts and neural systems of the brain that process signed languages and their silent grammatical units. The stunning biological equivalence that characterizes spoken and signed languages teaches us that human language does not require sound. This equivalence lays bare surprising universals of human language that challenge our assumptions and change our minds about the requirement that human language be tied to speech.

Scientific Evidence: The brain does not discriminate against modality, such as whether language is on the hands in signed languages or on the tongue in spoken languages. Despite radical modality differences, both signed and spoken languages share fundamental brain parts and neural systems in the processing, acquisition, and representation of natural language (Corina, Hafer, & Welch, 2014; Corina & Knapp, in press; Conference presentation Emmorey, 2011; Penhune, Cismaru, Dorsaint-Pierre, Petitto, & Zatorre, 2003; Petitto, 2000; Petitto, 1999; Petitto, 1997; Petitto, 1994; Petitto, 1992; Petitto & Bellugi, 1988; Petitto, Zatorre, Gauna, Nikelski, Dostie, & Evans, 2000).

Neuroimaging studies of deaf adults who sign and hearing adults who speak have shown that signed and spoken languages are processed in largely the same brain tissue and brain systems (Corina & Knapp, 2006; Conference presentation Emmorey, 2011; Emmorey, 2013; Emmorey, McCullough, & Weisberg, 2015; Emmorey, Weisberg, McCullough, & Petrich, 2013; Morford, Wilkinson, Villwock, Piñar, & Kroll, 2011; Petitto, Zatorre, Gauna, Nikelski, Dostie, & Evans, 2000; Williams, Darcy, & Newman, 2015). This even involves brain tissue and neural systems that were thought to be uniquely evolved for speech because these brain systems were located near the human ear (cf. Petitto, Zatorre, Gauna, Nikelski, Dostie, & Evans, 2000; Penhune, Cismaru, Dorsaint-Pierre, Petitto, & Zatorre, 2013). For example, studies have shown that sign-phonetic and sign-syllabic units in signed languages are processed in the identical neural tissue and systems as sound-phonetic units in spoken languages (cf. Petitto, Zatorre, Gauna, Nikelski, Dostie, & Evans, 2000; Emmorey, McCullough, & Weisberg, 2015; Emmorey & Petrich, 2012; Emmorey, Weisberg, McCullough, & Petrich, 2013; Kovelman, Shalinsky, Berens, & Petitto, 2014; Kovelman, Shalinsky, White, Schmitt, Berens, Paymer, & Petitto, 2009; for a review see Petitto et al., 2016). To be sure, shared neural sites and systems across speech and sign have been observed for all other levels of language organization as well (e.g., syntax, semantics, morphology). While select neural differences are of course observed, they are *predicted* stemming from typological differences seen across any two languages such as Chinese and English.

Policy Implications: Speech is *not* biologically superior to sign. The parts of the brain that process spoken languages are not privileged spoken language processing sites, nor are they fundamentally different from where signed languages are processed. Instead, spoken and signed languages are processed in similar brain tissue and neural systems. The biological equivalence of signed and spoken languages compels society and educational policy to give signed language the identical rights and legal protections as all spoken languages. It encourages us to embrace new ways to incorporate signed languages into the early education (as above, one that involves early bilingual sign + speech education) for all young deaf children especially those receiving Cochlear Implants.

MYTH 4: *Early bilingual language exposure causes language delay and language confusion. It is best to stabilize children first in one language (often called the "mother tongue"), followed by the other. Similarly, for deaf children, it is best to expose the child to a spoken language first, and then when it is "safe," permit exposure to a signed language, if absolutely necessary.*

Lessons Learned from Science: Decades of research have shown that early exposure to two or more languages does *not* cause language delay and language confusion. Neuroimaging and behavioral findings suggest strong evidence for *sensitive or critical periods* of development when learning two or more languages in early life that are identical to the famous *sensitive or critical period* governing monolingual language acquisition. Early bilingual language exposure—whereupon both languages are provided within the identical key early "sensitive periods" of all human language acquisition—is most optimal over later dual language exposure. The age at which a child is first exposed to their two languages (called, Age of first bilingual language exposure, or AoE) is vital to receiving brain, language, and reading processing advantages—advantages reported to persist spanning life. Early bilingual language exposure is a key *predictor* of children's language, reading, and literacy success. Contrary to a prevailing myth, signed languages do *not* develop on a different maturational timetable from spoken languages. In fact, early exposure to a signed and a spoken language—which constitutes early *bilingual* language exposure—affords the most stunning language and reading benefits to young deaf children, even those deaf children slated for Cochlear Implants, and even those deaf children receiving intensive speech training.

Scientific Evidence: Decades of scientific investigation have shown that early exposure to two languages does *not* cause language delay and language confusion (Holowka, Brosseau-Lapré, & Petitto, 2002; Jamal, Pichie, Napoliello, Perfett, & Eden, 2012; Jasińska & Petitto, 2013; Jasińska & Petitto, 2014; Kovelman, Baker, & Petitto, 2008a; Kovelman, Berens, & Petitto, 2013; Kovelman, Salah-Ud-Din, Berens, & Petitto, 2015; Mayberry, Giudice, & Lieberman, 2011; Mayberry & Lock, 2003; VL2 published Research Brief No. 7: Fish, S. & Morford, J. P., 2012, "Benefits of Bilingualism").

Bilingual children exhibit the identical *sensitive or critical periods* of development when learning two or more languages in early life as has been observed in monolingual language acquisition (Petitto et al, 2001; Petitto et al., 2012). The brain gains significant benefits (advantages) from early exposure to two languages. Early-exposed bilingual language learners show language processing and reading enhancements in each of their two languages (e.g. Jasińska & Petitto, 2013, 2014) as compared to monolingual childhood peers, which can continue across the lifespan (Allen, 2015a; Allen, Letteri, Choi, & Dang, 2014; Conference presentation Allen & Morere, 2016; Allen & Morere, 2012; Jasińska & Petitto, 2013; Jasińska & Petitto, 2014; Mayberry, Giudice, & Lieberman, 2011; McQuarrie & Abbott, 2013; Conference presentation McQuarrie & Enns, 2015; McQuarrie & Parrila, 2014; Petitto & Kovelman, 2003; Conference presentation Petitto, Langdon, & Stone, 2015; Stone, Kartheiser, Hauser, Petitto, & Allen, 2015; VL2 published Research Brief No. 7: Baker, S., 2011, "Advantages of Early Visual Language").

Infancy and early childhood are the best times of life to be exposed to two or more languages (Petitto, 2009; Petitto, 2005; Petitto, 2000; Petitto et al., 2001; Petitto et al., 2012). Deaf children exposed to a signed language and a spoken language have been shown to be indeed “bilingual children” and to receive all such bilingual language and reading advantages. To be sure, early bilingual exposure to a signed language and a spoken language is optimal (e.g., Petitto, 2009; Petitto et al. 2001). The idea that signed languages have a different developmental time window and thus may be exposed to a child later in development is a myth and one that can be most devastating developmentally.

In fact, more equals more. More exposure to language(s) means more communication, more vocabulary, more language learning agility, more world knowledge (greater comprehension), more readiness for reading and literacy, and, most fascinatingly, greater (more robust) neural recruitment of the brain’s classic language processing areas. The greater/more robust neural recruitment observed in the bilingual brain (as compared to monolinguals) is now widely referred to as the “Neural Signature” of the bilingual brain. For the original discovery of the brain’s neural signature for bilingualism *depending on the age of first bilingual language exposure* see Kovelman, Baker & Petitto (2008b). (See also Kovelman, Baker & Petitto, 2008a as well as Jasińska & Petitto, 2014; Jasińska, & Petitto, 2013; see also, Kovelman, Berens, & Petitto, 2013; Kovelman, Salah-Ud-Din, Berens, & Petitto, 2015; Mayberry, Giudice, & Lieberman, 2011; McQuarrie & Abbott, 2013; Conference presentation McQuarrie & Enns, 2015; McQuarrie & Parrila, 2014; Petitto & Kovelman, 2003; Conference presentation Petitto, Langdon, & Stone 2015; Stone, Karthesier, Hauser, Petitto, & Allen, 2015; VL2 published Research Brief No. 7: Baker, S., 2011, “Advantages of Early Visual Language.”).

Policy Implications: Parents and educators can be confident in the benefits of learning and using multiple languages as early as possible with all children. With deaf infants, spoken language + signed language bilingual language learning launches infants on the path to becoming healthy bilinguals with particularly strong spoken language and reading skills.

MYTH 5: *To be a good reader, students with bilingual language knowledge must practice harder at only the majority language skills (for example, drilling and practice in only spoken English, writing English, and reading English in students who also use another language, such as a natural signed language).*

Lessons Learned from Science: Practicing harder at only the majority language is not the most optimal way for all students with knowledge of other languages to become good readers. To be a good reader in, for example, the majority language English (e.g., USA, Great Britain, Australia, and other countries) students gain great benefit from having competence and practice in the other languages that they know. Deaf students will be better readers in English if their American Sign Language grammatical knowledge and skills (ASL; the signed language used in the United States) are also studied and enhanced through formal instruction. This is identical to discoveries about the optimal contexts for bilingual language learning in, for example, young children acquiring Spanish and English. Here, the greatest language learning advantages are afforded to children when *each* of their two languages are learned, studied, and used in rich and varied communicative ways, when each language is regarded as equal in social status, and when bilingual language schooling occurs using a balanced "50-50" bilingual language approach.

Scientific Evidence: Studies of *skilled* deaf readers have found that they develop *multiple pathways* to successful reading that are drawn not only from the majority language but also from competence in their other language as well—typically, a natural signed language. These multiple pathways include the use of visual sign phonological segmentation and patterning from their native signed language, orthographic patterning on the page, and use of other cues to decode English print (semantic, syntactic, and other cues depending on degree of hearing). Most common across these studies is that all children need access to the patterning at the heart of language in early life to facilitate a cascade of other developments that are central to learning vocabulary, language learning, and reading success. Thus, the exclusive focus on drilling in only one language, for example, English, is not optimal. Research shows that early sign-exposed deaf children have a larger vocabulary size in English and at a younger age than hearing children, and are ready to write letters earlier than hearing children because of their early experience with signed language and its systematic patterning. In fact, these students are bolstered by their proficiency in ASL and fingerspelling patterning, which in turn strengthens their literacy skills in English (Petitto et al., 2016; VL2 published Research Brief No. 1: Baker, S., 2010, "The Importance of Fingerspelling for Reading").

Surprisingly, some early sign-exposed deaf children have been observed to become faster and more accurate readers than age-matched (monolingual) hearing peers. Most common across these studies is that the early sign-exposed deaf child's access to rhythmic temporal patterning at the nucleus of human language phonological structure and segmentation (which the human brain has peaked sensitivity to in early life; Petitto et al., 2016) facilitates a cascade of developments that are central to vocabulary and language learning, and reading success, thus rendering the deaf child's advantage over the (monolingual) hearing child (Allen, Letteri, Choi, & Dang, 2015; Conference presentation Allen & Morere, 2016; Goldin-Meadow & Mayberry, 2001; Conference presentation Piñar, Dussias, & Morford, 2011; Mayberry, Giudice, & Lieberman, 2011; McQuarrie & Abbott, 2013; Conference presentation McQuarrie & Enns, 2015; McQuarrie & Parrila, 2014; Miller, Kargin, Guldenoglu, Hauser, Rathmann, Kubus, & Superegon, 2012; Morford, Kroll, Piñar, & Wilkinson, 2014; Morford, Wilkinson, Villwock, Piñar, & Kroll, 2011, VL2 published Research Brief No. 4: Morere, D., 2011, "Reading Research and Deaf Children"). Furthermore, deaf children with greater ASL proficiency use more English words in their writing than deaf students who have lower ASL proficiency.

Policy Implications: Exclusive focus on drilling in only one (majority) language in bilingual and multi-language users is not optimal. It is now understood that building language skills in each of a bilingual child's languages will provide powerful reading advantages, especially to the target majority language. Likewise, building both signed language and spoken language skills in a deaf student can render powerful reading advantages in the target majority spoken language.

MYTH 6: *Early signed language exposure "colonizes" the part of the brain needed to process speech and sound, damaging a deaf child's chances of learning spoken English.*

Lessons Learned from Science: Learning a signed language does not "colonize" the part of the brain needed for processing speech and sound. The young deaf child does not lose the brain tissue and systems required to develop the ability to process sound and spoken language if the child first receives early exposure to a signed language. The human brain recruits a generally similar network of neural systems that do their job of processing human language, and they do so irrespective of the specific spoken language that the child is learning (be it French, Swahili, English, Chinese, etc.) and irrespective of the modality of the language (be it spoken or signed). Early exposure to a signed language does *not* damage a deaf child's chances of learning another language, such as spoken English. In fact, for the young deaf child, early exposure to a signed language is powerfully facilitative for acquiring another language, such as spoken English, and it provides a powerful bridge to learning the other language. Here's why: *If the language is spoken only,* many young deaf babies around the world do not have useable access to the crucial rhythmic temporal (phonetic-syllabic) patterning of human language during the key sensitive periods of brain development and language processing, inclusive of 3 core maturational periods, ages 6-8 months, 8-10 months, 10-12 months. By contrast, *if the language is signed*, the deaf baby has available to it highly useable and accessible rhythmic temporal (phonetic-syllabic) patterning at the heart of all world languages, which is present in signed languages, and which can be made available through exposure to a signed language during the correct sensitive periods in brain development (above). Ironically, early sign language exposure in the young deaf baby is the biological "magic bullet" that keeps open ("wedges open") the brain's capacity to perceive and learn the language patterning that is crucial for normal healthy vocabulary and language learning, language comprehension, and decoding in early reading.

Scientific Evidence: Early exposure to signed language appears to act as a biological "wedge" that opens up — and keeps open — the brain's capacity to learn language patterning at the heart of spoken and written English (Emmorey, 2013; Emmorey et al., 2015; Kovelman et al., 2009, 2014; Petitto et al., 2012; Petitto et al., 2016; see also Petitto et al., 2012 for a discussion of these issues regarding children who are exposed to two spoken languages, such as in the bilingual brain).

A fascinating fact about human brain organization and language processing is that there is <u>*not*</u> vast neural reorganization of brain structures and their functions regarding the world's different languages (be they spoken or signed). Instead, largely similar brain structures are used across all world languages despite different language typologies; although select neural differences do exist, they are *predicted* stemming from typological differences seen across any two language pairs, such as English (non-tonal) versus Chinese (tonal; for example, whereupon there is greater recruitment of right hemispheric parietal regions known to mediate prosody/tonal variation as compared to English).

Among the most stunning similarities observed across languages— including across signed and spoken languages —involves brain structures previously assumed to be the exclusive site for processing sound for the past 100 years. The left hemisphere's Planum Temporale (PT) in the Superior Temporal Gyrus (STG) has been understood to process sound phonetic-syllabic information in spoken languages. However, this identical brain structure (PT/STG) has been discovered to do the identical job (to have the identical function) in human signed languages, whereupon it processes *sign* phonetic-syllabic units (Emmorey, 2013; Emmorey et al., 2015; Petitto, Zatorre et al., 2001; Penhune et al., 2003).

Such surprising similarities in the brain organization across all human languages have led researchers to question the view that early exposure to one language (such as a signed language) will "colonize" (take over and/or push out) the neural representation of another language (such as spoken English). They hypothesized that, if this were true, then deaf adults who had received Cochlear Implants very early in life *with exclusively spoken language training* should have more *typical* brain organization for language (that is, more like a hearing person's brain organization and similar good language processing skills as a hearing person). By contrast, deaf adults who received Cochlear Implants very early in life but who had *very early signed language exposure first*, then followed by spoken language training, should show more *atypical* (abnormal) brain organization for language (that is, less like a hearing person's brain organization, and with poorer language processing skills as compared to a hearing person). In this latter case, researchers specifically tested the hypothesized view that the early exposure to signed language would push out or colonize the neural tissue for processing speech, thereby rendering their English language processing atypical as compared to hearing people.

One recent brain imaging study is revealing, with more studies to come: The team found that deaf adults who learned signed language first in early life, followed by early-life cochlear implantation and intensive spoken language/speech training, showed the most typical (normal) brain and auditory tissue processing for English as compared to a hearing person's brain processing English. By contrast, deaf adults who received exclusively cochlear implantation with intensive spoken language therapy, showed the most atypical (abnormal) auditory tissue and brain activity during the processing of English as compared a hearing person's brain processing English. The researchers reasoned that the deaf participants with "typical" brain activity while English language processing, showed this typical activity because they had had early exposure to the patterns of human language during the right sensitive periods, albeit made available to them via early exposure to a natural signed language. Moreover, these participants effectively were in a "bilingual" language-learning context, and thus they received all of the language processing benefits classically reported in bilinguals. Rather than hurting their processing of spoken English, the early exposure to signed language had kept key neural tissue active, bridging them to language success once exposed to spoken English. (see Conference presentation Jasińska, Langdon, & Petitto, 2013; VL2 published Research Brief, No. 7, Fish, S. & Morford, J. P., 2012, "The Benefits of Bilingualism").

Researchers have further discovered that having a strong language foundation in a signed language (e.g. American Sign Language, ASL) correlates with stronger speech abilities for deaf children who can also access speech through hearing aids or Cochlear Implants (VL2 published Research Brief No. 6: Mitchiner, J., Nussbaum. D. B., & Scott, S., 2012, “The Implications of Bimodal Bilingual Approaches for Children with Cochlear Implants”). Multiple studies have also shown that deaf children and adults with early exposure to sign, speak better (Allen, 2015a; Allen & Anderson, 2010; Conference presentation Allen & Morere, 2016; Emmorey & Petrich, 2012; McQuarrie & Abbott, 2013; Conference presentation McQuarrie & Enns, 2015; McQuarrie & Parrila, 2014; Singleton, Morgan, DiGello, Wiles, & Rivers, 2002; Stone, Kartheiser, Hauser, Petitto, & Allen, 2015; Traxler, Corina, Morford, Hafer, & Hoversten, 2013). Other studies have found that early ASL-English bilingual (bimodal) language exposure does *not* block the development of speech, but late exposure to an accessible language can render powerful impairments to language and higher cognitive development (Morford & Hänel-Faulhaber, 2011).

Policy Implications: Parents and educators need not fear that early exposure to signed language will damage a deaf child’s chances of learning spoken English. Nor does exposure to a signed language (such as ASL) “take over” the part of the brain needed for processing speech and sound. To achieve the benefits to speech and spoken language, it is essential that signed language exposure is provided during the early life “sensitive periods” for language. Exposing a young deaf baby to signed language during key sensitive periods prior to its cochlear implantation and formal speech and spoken language training, in turn, “wedges” open — and keeps open — the brain’s capacity to learn the patterning of spoken language.

MYTH 7: *The brains of deaf children are disabled at birth. Development of these children is best viewed as growth of a disabled child.*

Lessons Learned from Science: The brains of deaf children are *not* disabled at birth. At birth, development of these children need *not* be viewed as growth of a disabled child. Using modern neuroimaging technology, researchers have observed that deaf and hearing infants' brains appear biologically comparable and comparably normal at birth. Yet one of the hallmarks of the human brain is that it can undergo remarkable change as a result of different experiences in early life. This capacity is known as neuroplasticity and it is widely understood to be particularly robust during the first 3 years of life. During this time, the human brain passes through multiple periods of brain growth and "sensitive periods" for human language development. If a child experiences *minimal language input* during this important time—or, worse, if the child has *no accessible language input* during this time—then their brains can be impacted. Under these circumstances, the deaf infant's initially "normal" brain at birth can undergo significant change impacting brain structures and their concomitant higher cognitive functions. What is important is that such brain changes need not have occurred, but they are induced based on whether a deaf child is exposed to an accessible natural language in early life, or not. Children in the latter category (those who receive *no accessible language input* in early life) include deaf children slated for Cochlear Implants, whereupon natural signed language is not made available during the large time gap between birth and the onset of surgery and speech training from around 12-18 months. Although a temptation might be simply to implant deaf infants even earlier in life, scientific study teaches us that this would be in error. Deaf infants undergo positive visual processing and attention advantages that afford greater vocabulary and language learning and reading advantages over age-matched hearing infants. Thus, a more powerful route would be to exploit these early visual processing advantages with early-life exposure to a visual signed language that catapults brain development forward and keeps core neural tissue and systems "open" during key sensitive periods for language processing, thereby readying the child for the acquisition of their other language, a majority spoken language, once such exposure occurs.

Scientific Evidence: With systematic early visual signed language exposure, mechanisms of neuroplasticity give rise to advantages in the young deaf child's cognitive processing over age-matched hearing children. Forty decades of research have shown many ways in which deaf children's brains can become quickly *advantaged* in early life if exposed to a visual signed language as part of early bilingual signed+spoken language learning. These children gain greater visual processing, visual attention, and visual gaze tracking advantages as compared to hearing children; in some cases, the hearing child had the initial visual processing capacity but lost it due to the absence of systematic visual patterned input (Dye, 2014; Dye & Hauser, 2014; Conference presentation Lieberman, Hatrak, & Mayberry, 2011; Lieberman, Hatrak, & Mayberry, 2014; Conference presentation Petitto, Langdon, & Stone, 2015; VL2 published Research Brief No. 3, Hirshorn, E., 2011, "Visual Attention and Deafness.").

The deaf child's greater visual processing can also be witnessed in their increased vocabulary, language processing (including greater semantic and world knowledge) and reading skills as compared to age-matched hearing peers (Allen, 2015a; Allen, Letteri, Choi, & Dang, 2014; Bochner, Christie, Hauser, & Searls, 2011; Holowka, Brosseau-Lapré, & Petitto, 2002; Mayberry & Lock, 2003; McQuarrie & Abbott, 2013; Morford & Carlson, 2011; Petitto, 2009; Petitto, Holowka, Sergio, & Ostry, 2011; Petitto, Holowka, Sergio, Levy, & Ostry, 2004; Petitto, Katerelos, Levy, Gauna, Tétrault, & Ferraro, 2001; Petitto & Marentette, 1991; Conference presentation Piñar, Dussias, & Morford, 2011; Singleton, Morgan, DiGello, Wiles, & Rivers, 2002; Supalla, Hauser, & Bavelier, 2014; William, Darcy, & Newman, 2015).

Another advantage due to the deaf child's enhanced visual processing is that these children exhibit increased cognitive flexibility and social self-regulation relative to hearing children of the same age (Corina, Chiu, Knapp, Greenwald, San-Jose-Robertson, & Braun, 2007; Freel, Clark, Anderson, Gilbert, Musyoka, & Hauser, 2011; Hauser, Lukomski, & Samar, 2013; Conference presentation Lieberman, Hatrak, & Mayberry, 2011).

Policy Implications: All children need early exposure to natural language(s), with devastating lifelong deleterious consequences if this is not the case. For example, children with minimal language input, or no accessible language input, during the early sensitive periods of language growth can have lifelong learning, language, and reading consequences (e.g., children raised in under-resourced contexts; children slated for Cochlear Implants, whereupon exposure to a natural signed language is not available; children with late bilingual language exposure, etc.). Helping educators and medical professionals to be aware of the advantages of early visual language exposure, in addition to speech, could spare many deaf and hard of hearing infants the adverse — even disabling — neurological and life impacts resulting from early language deprivation that can be caused by early exposure exclusively to speech.

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In this article, seven of the most common myths associated with the learning capacity of young children are evaluated, particularly, young deaf children around the world. Drawing from scientific discoveries in the Science of Learning, these myths were debunked, followed by discussion of the impact that this new scientifically based knowledge has for educational policy. Although the myths were associated with deaf children, the present work lays bare the universals of language learning in all children, the optimal conditions for becoming bilingual in all children, and the multiple routes that all children can benefit from to become a skilled and successful reader.

Presently, many deaf babies worldwide slated for Cochlear implantation receive no useable systematic language input until after the implantation surgery is completed, the device is correctly tuned, and speech training begins—which can take up to age 18-26 months or more. Here, exposure to the systematic patterns of natural language is effectively “held back” from the child until well past key sensitive periods in brain and language development, after which access to spoken language and speech is finally begun. By analogy, we would never encourage a family in, for example, France, to stop speaking to their newborn hearing baby in the majority language, French, even if the family planned to move to the United States when the child reached age 18 months (where the majority language will be English). In the treatment of human children around the world, we would be very hard pressured to find other examples where something as vital to the species’ survival and brain development as human language is *held back* from a child this long. This worldwide practice is especially surprising because of the decades of scientific evidence that have demonstrated the devastating and deleterious impact that *minimal language input* in early life can have on a child's higher cognition, language, and reading success.

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