New Discoveries From the Bilingual Brain and Mind Across the Life Span: Implications for Education

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ABSTRACT—We discuss the fruits of educational neuroscience research from our laboratory and show how the typical maturational timing milestones in bilingual language acquisition provide educators with a tool for differentiating a bilingual child experiencing language and reading delay versus deviance. Further, early schooling in two languages simultaneously affords young bilingual children a reading advantage and may also ameliorate the negative effect of low socioeconomic status on literacy. Using powerful brain imaging technology, functional Near Infrared Spectroscopy, we provide a first-time look into the developing brains of bilingual as compared to monolingual children. We show unequivocally that the age of first bilingual exposure is a vital predictor of bilingual language and reading mastery. Accounts that promote later dual language and reading instruction, or those that assert human brain development is unrelated to bilingual language mastery, are not supported by the present findings. We discuss the implications for education, teachers, and developmental brain sciences.

A core question in educational neuroscience research is to understand whether there are “sensitive periods” in human language and reading development, and to crack the code regarding the development of the brain tissue and its related functions that, as a consequence of vital interactions with the environment, mediate the remarkable human language capacity across the life span. We have dedicated ourselves both to launching the discipline as well as to promoting educational neuroscience, an exciting and timely new field that provides a most relevant level of analysis for addressing today’s core problems in education. Educational neuroscience, known for being a multidisciplinary endeavor, draws empirical strength from several disciplines, in particular, cognitive neuroscience, which combines decades of experimental advances from cognitive, perceptual, and developmental psychology with a variety of contemporary technologies for exploring the neural basis of human knowledge over the life span.

Whether knowledge of brain functions and learning can be used to benefit education has been a topic of great controversy over the past decade (Geake, 2003; Geake & Cooper, 2003; Goswami, 2004; Ito, 2004; O’Boyle & Gill, 1988; Petitto & Dunbar, 2004). Some have argued that studies in neuroscience are so far removed from educational practice that they have little relevance to education (e.g., Bruer, 1998, 2002, 2003). This has spurred an understandable worry in the education community that research on brain function is not relevant to education. Here, we will show how language research, be it in monolinguals or bilinguals, in educational neuroscience has the fullest potential to fundamentally advance contemporary educational policy and practice—and soon. We will show how key studies involving the learning of language (especially learning two languages as in childhood bilingualism) offer a new understanding of the timing, sequencing, and methods of learning these core content areas in education that in turn can influence the quality and methods of teaching and instruction. The fundamental premise within is that modern studies of the brain, language processing, reading, and how multiple languages are learned can (1) reveal vital information about timing in education (i.e., when exposure to core content optimally learned), (2) tell us about the mechanisms and the developmental sequence that underlie the learning of core content, and (3) suggest ways of learning
and teaching that can be used to circumvent problems associated with traditional teaching methods, as well as language remediation—and especially novel here, bilingual language remediation (Kovelman, Berens, & Petitto, 2006 in preparation).

In focusing our beacon on language learning and reading in young bilinguals as compared to monolinguals, we find considerable controversy in education over the past 50 years. Here, the “hold-back” approach has dominated the lion’s share of childhood bilingual education over the decades (Petitto et al. 2001b). Here, it had been assumed that young children from nonmajority language homes and cultural backgrounds must be given a strong base in one language (e.g., English) before receiving instruction in their other language (e.g., Spanish), or vice versa, for fear that the child’s home language might disrupt full acquisition of the other majority language. (Note that similar logic underlies why most monolingual children in the United States’ public schools are not introduced to a “foreign” or second language until high school.) Implicit in the “hold-back” approach are assumptions about timing (when content should be introduced) and sequencing (what content must come first before exposure to other content, which carries additional presuppositions about the direction that conceptual mapping and/or transfer of knowledge in human learning obligatorily flows). These assumptions, in turn, have directly affected prevailing methods of instruction and curricula in teaching language, even though educators are highly aware that our students are having great difficulty in learning second languages later in the school years.

As such, there is an overall logic to our research path within. English language only programs have been instituted based on assumptions about how children will learn the majority language best. Here, intensive instruction of the majority language (at the exclusion of instruction in the child’s home language) is thought to be best for English language and reading mastery. The goal of this educational program, as well as the outcome for a student, is typically not for the child to have bilingual language and reading mastery; instead, the goal is for them to have high language and reading competence in one language only, English. Despite the best intentions, the fact that many of the children who are English Language Learners experience language and reading problems is well known (August, Carlo, Dressier, & Snow, 2005; and see national reports on studies of this population in August & Shanahan, 2006; Lesaux, Koda, Siegel, & Shanahan, 2006; Lesaux, Lipka, & Siegel, 2006). Thus, we sought to test the “hold-back” hypothesis implicit in this educational approach by studying the reverse case: Children receiving instruction in each of their two languages (home language and new majority language) during the same developmental period. Indeed in this paper, our goal was to study these “bilingual” children in early life, and later as adults. Bilingual is defined here as adults who had early, intensive, and maintained dual language exposure and who use their two languages in their adult daily life. Very young bilingual children are defined as those in bilingual home and educational programs where the goal is for them to achieve equal and equally high language and reading competence in each of their two languages (home and majority).

Because real life typically does not present us with ideal circumstances, for example, all children are not exposed to perfectly balanced dual language input from birth (e.g., Petitto et al., 2001b), we especially examined children whose age of first intensive and maintained bilingual exposure varied in more natural ways, with particularly close attention to those ages of first bilingual language exposure understood to be important for brain development and its sensitive periods of maturation and myelination (cf. Lenneberg, 1967). Strictly speaking, in this way, even our later dual language learners, say, children’s whose first intensive and maintained exposure to two languages comes at age 9, would not be judged “L2 learners.” This is because the goals of these children’s educational programs, as well as their families, is that they be educated, and fully and equally competent in each of their languages, as opposed to the more traditional notion of a child who, say, immigrates to a new country and enters a monolingual school in the new L2 language.

Our path of investigation below is broad, spanning young infants, school age children, and adults. We also use both behavioral and brain scanning technologies (functional Magnetic Resonance Imaging [fMRI], functional Near Infrared Spectroscopy [fNIRS]) to gain exciting and useful new insights into what students are learning and when, why they have difficulties in learning particular content areas, and what might be new forms of instruction that can facilitate learning.

**BILINGUAL LANGUAGE LEARNING AND READING**

For nearly a century, parents, educators, and scientists have been of two minds about the bilingual child. This phenomenon is so pervasive that our lab has come to call it “the bilingual paradox” (Petitto et al., 2001b). We freely marvel at the seemingly effortless ways that young children can acquire two or more languages simultaneously if exposed to them in early life. At the same time, we view early simultaneous bilingual exposure with suspicion, fearing that exposing a young child to two languages, too early, may cause language delay, and worse, language confusion. Indeed, the general perspective that young children are somehow harmed by bilingual exposure that occurs “too early” is reflected both in educational settings and in comments made by the many parents raising bilingual children who visit our laboratory. As support for this view, some have invoked the dreaded notion of “language contamination” that ostensibly results from early exposure to another language (e.g., Crawford, 1999). For example, in many educational settings in the United
States, the fear that exposing a child to a new language (in addition to the majority language, such as English) or to two languages simultaneously (such as English and Spanish) too early may interrupt “normal” language development in the majority language (e.g., English), is reflected in contemporary educational practice. Most generally, we see this reflected in the fact that many children in the United States receive their first formal schooling in another language in high school, well after the developmentally crucial toddler years for language learning. More specifically, we see this reflected in the fact that bilingual policy in some U.S. States (e.g., Massachusetts) has undergone a dramatic policy reversal, whereby Spanish is withheld from young children from Spanish-speaking homes in their public-school classrooms, which now must be conducted in English-only. Following this general spirit, parents visiting our laboratory often opt to “hold back” one of the family’s two languages in their child’s early life. They believe that it may be better to establish one language firmly before exposing their child to the family’s other language so as to avoid confusing the child. They also worry that very early bilingual language exposure may put their child in danger of never being as competent in either of the two languages as monolingual children are in one (Petitto et al., 2001b).

To shed light on such “hold-back” views, researchers have examined the impact that acquiring two languages simultaneously has on very young children in early life. Two general classes of hypotheses have dominated the field, each echoing one side of the bilingual paradox. Genesee (1989) first termed these two classes of hypotheses the “unitary” and “differentiated” language system hypotheses. In the unitary language system hypothesis, researchers assert that children exposed to two languages initially have a single “fused” linguistic representation (they don’t know that they are acquiring two languages), and that they only begin to differentiate their two native languages around age 3 and beyond (e.g., Redlinger & Park, 1980; Vihman, 1985; Volterra & Taeschner, 1978). The assertion that bilingual children’s initial linguistic knowledge is “fused” implies that they undergo protracted (or delayed) language development (relative to monolingual peers) until they sort out their two input languages during early life. Indeed, for nearly two decades, one prevailing hypothesis in the scientific literature that spread into educational policy was that bilingual children do not initially differentiate between their two input languages and are thus slower—more delayed overall—in language learning as compared to their monolingual peers. By contrast, researchers who advocate the differentiated language system hypothesis assert that bilingual children can and do differentiate their two input languages (Genesee, 1989; Genesee, Nicoladis, & Paradis, 1995; Lanza, 1992; Meisel, 1989, 2000), although the question of precisely when (what age) remains unanswered (see studies by Petitto below).

**Bilingual Maturational Timing Milestone Studies**

In this series of studies, we tested hypotheses of delay and confusion in very young bilingual language learning, and examine indices of when (what age) bilingual language differentiation begins. In this first series of cognitive and developmental psychology behavioral studies, we investigated the impact of the age when a bilingual child is first exposed to a second language on the child’s dual language mastery. That is, where first bilingual exposure occurs from birth as compared to first dual language exposure from age 3, from age 5, from age 7, or from age 9, whereupon the ages correspond to key ages of brain myelination and maturation.

To increase the generalizability of our findings, our studies by design are inclusive and typically entail an experimental cross-sectional design in combination with a longitudinal design, and they are always cross-linguistic. Indeed, in some instances they are even cross-modal, as included in some of our research populations were a fascinating group of young bilinguals: hearing children exposed to a spoken and a signed language (for example, young bilingual children acquiring English and American Sign Language). These children are indeed “bilingual” as has been empirically established by many scientists spanning four decades (e.g., see Petitto et al., 2001b, for a review and a discussion as to why we are justified in considering such children as being fully “bilingual” in the identical manner as children learning, say, Spanish and English from birth). Our participant samples were always matched using standard assessment indices of Socioeconomic Status (SES). We indeed drew children from diverse SES designations (including “high” and “low”) and from two countries, United States and Canada, as well as from diverse regions of these countries, including rural and urban. Child participants were always of matched ages and possessed comparable cognitive functioning (as assessed through our standardized tasks) and were of good health, full-term babies, and free of known neurological/psychological illnesses. Together, our studies involved several experimental groups, including monolingual children acquiring either one spoken language or one signed language, and bilingual children acquiring two spoken languages, or a signed and a spoken language, or two different signed languages (e.g., American Sign Language and Langue des Signes Quebecoise used among culturally French Deaf people in Quebec and other culturally French Deaf communities across Canada; Petitto & Holowka, 2002; Petitto & Kovelmsn, 2003). Further, the language combinations that the children were acquiring spanned many different languages. For example, taken together, the discoveries summarized below involve combinations of bilingual children acquiring Spanish and English, French and English, American Sign Language and English, Langue des Signes Quebecoise and French, Russian and French, and so forth. In general, information about the specific details associated with each of the studies in this...
behavioral section, as well as all of the other studies discussed below concerning the children and adult participants’ specific language backgrounds, language use and language community contexts, and other important details of their SES, age, dual language maintenance, language preferences, language dominance, and the like, as well as the empirical methods by which all such information was rigorously gathered and assessed, can be found in the individual articles cited in each summarized research section.

In these studies, no participant could be classified as an “English Language Learner.” In the United States of America, this is a term typically used to refer to a child from one home language background, say Spanish, who arrives at Kindergarten (and/or school grades beyond) and who is educated exclusively in the majority language, English. For many of these children, their formal language education begins with the introduction of English (again, in Kindergarten and/or beyond), is exclusive to English, and is accompanied by little or no formal language and reading instruction in their native home language (e.g., Spanish) after the onset of English training. Hence, they have been termed “English Language Learners.” Rather than being English Language Learners, all children and adult participants in the present studies summarized would be classified as “bilingual”—specifically, those defined as those individuals with dual language exposure, dual language education (in language, reading, social studies, etc.) and, crucially, dual language maintenance over the life span.

Our behavioral studies sought to investigate a variety of scientific and educationally important questions involving (1) the optimal age of first bilingual language exposure, (2) how long it takes for bilingual children to achieve mastery in a new language depending on the age of first bilingual language exposure and the type of language learning environment (home, community, classroom), (3) the development of linguistic milestones in bilingual children, because it is important to know what constitutes “normal” language acquisition in a bilingual child as compared to widely known monolingual norms, (4) the normal/typical stages of bilingual language development, which helps teachers identify when a bilingual child is truly “language delayed” because of a language impairment versus simply undergoing the normal/typical sequence of bilingual language development, and (5) the impact of the introduction of a new language on a child’s first/home language, which addresses the important educational question of language attrition; does learning a new language harm the old?

We found that (1) early (before age 5) bilingual language exposure is optimal for dual language development and dual language mastery (Kovelman & Petitto, 2002). (2) At the same time, those bilingual children who were first raised monolingual from birth and who were then exposed to a new language beginning from ages 3, 5, 7, to 9 years did achieve the morphological and syntactic fundamentals of the new language within their first year of exposure. Importantly, however, we found that the rapid acquisition of new language fundamentals was possible only when three key factors occurred: Exposure to the new language had to be extensive, systematic, and across multiple contexts. For example, we observed that the community and home were most optimal learning contexts, with far less optimal dual language mastery being achieved if exposure came exclusively within the classroom (or “instructional;” Kovelman & Petitto, 2003; Petitto, Kovelman, & Harasymowycz, 2003). (3) Bilingual children exposed to two languages from birth achieved their linguistic milestones in each of their languages at the same time and, crucially, at the same time as monolinguals (Holowka, Brosseau-Lapré, & Petitto, 2002; Kovelman & Petitto, 2002; Petitto & Kovelman, 2003; Petitto et al., 2001b). (4) Bilingual children exposed to their new language between 2 and 9 years of age exhibited “stage-like” language development in their new language. Surprisingly, this stage-like development is highly comparable in content to the stage-like language development typical of monolingual children acquiring the language from birth, differing of course in the age when it occurs given the later exposure to the child’s other language (Kovelman & Petitto, 2003). (5) Importantly, introduction of the new language did not “damage” or “contaminate” the home language of the child (Petitto et al. 2003).

Bilingual Infant Language Phonetic Perception

Having found behavioral evidence that young bilinguals can differentiate their two languages from as early as the onset of first words (production studies), we turned to explore the phonetic discrimination abilities in perception in bilingual babies even before they could babble. (For bilingual babies involving either two spoken languages, or a signed and a spoken language, see Dubins, Berens, Kovelman, Shalinsky, & Petitto, 2009; Norton, Baker, & Petitto, 2003; for monolingual babies and adults involving either spoken languages, or signed languages, see Baker, Sootsman, Petitto, & Golinkoff, 2003; Baker, Michnick-Golinkoff, & Petitto, 2006; Baker, Idsardi, Golinkoff, & Petitto, 2005; Dubins et al., 2009; Petitto, 2007; White et al., 2008; for papers related to early phonetic processing/babbling see also Petitto & Marentette, 1991; Petitto, Holowka, Sergio, & Ostry, 2001a.) These studies used either the classic infant controlled habituation paradigm (Cohen, 1972) in Petitto’s Infant Habituation Lab or the Habituation paradigm in combination with new brain imaging technology in our lab, called fNIRS (discussed below). We examined the abilities that young bilingual and monolingual babies have for processing phonetic units, which are crucial to successful phonological segmentation of words, language learning, and later reading. We also investigated whether bilingual infants achieve developmental milestones for phonetic perception at the same ages as monolingual infants by testing bilingual babies’ phonetic perception at two
developmentally important ages, 4 months and 14 months. From birth to around age 4 months, monolingual babies have been shown to have the capacity to discriminate categorically the smallest “building blocks” of language—the phonetic units such as in [ba] [da]—from any of the world’s languages. By around age 14 months, however, they lose this universal capacity, and, instead, hone in on the phonetic inventory of their native language with increased precision (e.g., Baker, Michnick-Golinkoff, & Petitto, 2006; Jusczyk, 1997). We especially wondered whether bilingual babies learning two languages show a similar pattern and developmental trajectory as monolingual babies, as evidenced in their behavioral phonetic discrimination abilities and neural tissue recruitment when learning the two sets of sounds in their two native languages.

We found that contrary to suggestions (e.g., Burns, Werker, & McVie, 2003), bilingual babies are not “different” (atypical, delayed) in acquiring phonetic contrasts. Instead, our experimental results suggested to us that early bilingual exposure yields a phonetic processing “bilingual advantage” (Norton et al., 2003). That is, relative to monolinguals, bilingual babies show an increased sensitivity to a greater range of phonetic contrasts, and an extended developmental window of sensitivity for perceiving these phonetic contrasts relative to monolingual children. This fascinating finding is under further study, as it suggests the possibility that bilingual phonetic perception in early life can function as a kind of “perceptual wedge” to keep open a child’s capacity to discriminate phonetic units, whereas the same capacity attenuates quickly and dramatically for the monolingual child in early life. Furthermore, these findings suggest that bilingual children should not experience difficulty with phonological word segmentation in two languages at the same time, a capacity that is crucial for language learning and, especially, for successful reading acquisition in two languages. Indeed, this hypothesis is returned to below in our comparative studies of the acquisition of reading in bilingual and monolingual children.

Imaging the Brains of Bilingual and Monolingual Infants

Having behaviorally explored young bilingual babies’ phonological processing, new tantalizing questions include: what types of neural tissue underlie this capacity? Is it specific to language or general auditory processing tissue? Does neural participation change over time, and could an understanding of the tissue that supports language processing in bilingual and monolingual infants help us identify all babies at risk for language problems, even before they utter their first words? The educational implications of this would be significant as, today, we must wait until babies grow older (around 3 years) before they are definitively diagnosed with language problems, which is often well beyond the time when phonological processing tissue has lost the ability to discriminate all possible phonetic units in world languages (again, by around 14 months, as they instead attain an increased ability to discriminate phonetic units within their native language; e.g., classic discoveries by Kuhl & Padden, 1983; Werker & Tees, 1983). Standardized behavioral tasks involving (1) visual perception, (2) speech recognition, and (3) native and nonnative phonetic perception were used with infants (mean age 3 months) while undergoing fNIRS recordings to test specific within-hemisphere neuroanatomical hypotheses about specific neural tissue (and networks of neural tissue) regarding their linguistic versus general perceptual processing functions. fNIRS is a noninvasive optical technology that, like fMRI, measures cerebral hemodynamic activity in the brain and thus permits one to “see” inside the brains of children and adults while they are processing specific aspects of a task. Unlike fMRI, fNIRS is small, highly portable (the size of a desktop computer), highly child-friendly, and can be used with alert babies. fNIRS is a closer measure of hemodynamic change than fMRI, as it provides information about oxygen rich (HbOxy), oxygen depleted (HbDeoxy), and total oxygen change (HbT), unlike fMRI that provides total Blood Oxygen Level Density/BOLD measures, and it has excellent spatial and temporal resolution. Although the depth of measurement into the brain that fNIRS can accomplish (~5 cm), is surpassed by fMRI (which can measure deep in the human brain), it is, nonetheless, ideal for the measurement of higher cognitive functions such as language. It is also quiet, free of the loud pings common to fMRI, and its tolerance of subtle movements makes it a stunning advance in the study of the full complement of human language, including language reception, speaking/signing language production, writing and reading across the life span.

Using fNIRS, we found robust activations in the brain’s classic language areas in very young bilingual and monolingual babies. Bilingual and monolingual infants showed the same recruitment of language-dedicated neural tissue (including, e.g., the Superior Temporal Gyrus, STG, for phonetic processing, the Left Inferior Frontal Cortex, LIFC, for word processing, as well as the primary visual occipital area, V1, for the sensory processing of nonlinguistic visual checkerboard; Petitto, 2003; Petitto, Baker, Baird, Kovelman, & Norton, 2004; see also Pena et al., 2003).

Fascinating brain changes were seen over early life depending on the baby’s age and the classic language milestone associated with this age. We observed brain changes according to the baby’s age, which were related to the achievement of well-known language milestones, provided among our first glimpses into the brain-based mechanisms that make possible the “developmental change” seen on the outside. The similarities between bilingual and monolingual babies’ brains and performance also suggested that bilingual infants hone in on their native language in similar ways, and on the same
time-table, as monolinguals. For example, the STG, known for
its key role in phonetic processing, was functioning even in
our youngest babies (∼2–6 months). Because of its early brain
activation, this finding suggests a biological foundation for the
phonological level of human language processing, and it further
suggests that this brain tissue may be mediating all infants’
universal phonetic discrimination milestones. Remarkably,
Broca’s area/LIFC, known for being the site of the brain where
we search and retrieve information about the meanings of
words, comes on-line later (∼10–14 months), and may govern
the first word milestone (Dubins et al., 2009, in preparation).

A further piece of converging evidence regarding the unique
status of the brain tissue related to phonetic processing comes
from another study of young monolingual babies; here, we
found that babies show different developmental trajectories in
the brain depending on whether the stimuli perceived were
linguistic/phonetic or nonlinguistic/tone sounds. In this series
of fNIRS brain imaging studies of adult and baby participants
processing native English language phonetic contrasts, Zulu
click syllables, and tones, English-speaking adults showed
reliable left lateralization for processing English phonetic
contrasts, but no lateralization differences for tones. A similar
pattern was observed in our youngest monolingual babies
(White et al., 2008), and a similar pattern was observed in our
bilingual babies (Dubins et al., 2009a,b; see also Dubins et al.,
in preparation).

These are very surprising findings in light of suggestions
from speech perception scientists who have argued that early
linguistic processing is not based on the processing of language
units. Instead, it is argued to be built up from general auditory
perceptual processes and, only later (around 6–8 months)
becomes linguistic (Jusczyk, 1997). These findings provide a
new window into the nature and timing of early language
processing in a way never before possible. These ongoing
brain imaging studies figure prominently in the type of
cognitive neuroscience studies that have great potential
to make significant contributions to education and early
remediation and will be returned to below in Educational
Implications.

Imaging the Brains of Bilingual and Monolingual Adults

Questions about whether a bilingual can ever fully acquire
two language systems, each with monolingual proficiency,
and debate over whether knowing two languages helps or
hinders the processing of either language, have led to one of
the most hotly pursued research areas among contemporary
language scientists. Despite the enormous interest, most
previous research has not involved direct study of language
and reading processing in the brains of bilinguals as compared
to monolinguals even though this question is vitally important to
our understanding of how best to educate bilinguals. Instead,
the lion’s share of research has focused either on language
processing in the brains of bilinguals who had early versus
late exposure to their two languages (Dehaene et al., 1997;
Friederici, Steinhauer, & Pfeifer, 2002; French-Mestre, Anton,
Roth, Vaid, & Viallet, 2005; Kim, Relkin, Lee, & Hirsch, 1997;
Klein, Watkins, Zatorre, & Milner, 2006; Mahendra, Plante,
Magloire, Milman, & Trouard, 2003; Marian, Spivey, & Hirsch,
2003; Perani et al., 2003; Weber-Fox & Neville, 1996, 2001),
language processing in bilinguals who have high proficiency in
each of their two languages versus those with low proficiency
in one of the two (Chee, Soon, Lee, & Pallier, 2004; De
Blaser et al., 2003; Majerus et al., 2008; Perani et al., 2003;
Wartenburger et al., 2003), or language switching in bilinguals
(Grosjean, 2001; Hernandez, Martinez, & Kohnert, 2000; Price,
Green, & von Studnitz, 1999; Paradis, 1997; Rodriguez-Fornells
et al., 2005; Rodriguez-Fornells, Rotte, Heinze, Noesselt, &
Muente, 2002). In these studies here, we directly compare
how the brains of bilinguals and monolinguals process
linguistic information to understand whether being bilingual,
per se, modifies the classic language-dedicated neural sites
and pathways underlying human language processing. Does a
bilingual brain, even when a bilingual is using only one
language, process linguistic information in the same manner
as a monolingual brain? We were especially interested in
tracking the trajectory of bilingual language development
into adulthood, by investigating the impact of the (1)
accommodation when bilingual adults were first exposed to their other
language on their brain’s neural organization. We were also
curious about any (2) brain differences that might exist between
bilingual and monolingual brains and particularly fascinated in
whether there is a “neural signature” of bilingualism. Finally,
we hoped to understand whether there are any (3) brain
differences within bilinguals based on the linguistic structure of
the two languages being learned. Using fMRI and fNIRS, we
examined the bilingual brain’s language organization while
performing language processing and reading tasks in each of
their languages and while switching between their languages,
in addition to examining their brain’s organization on a variety
of higher cognitive and executive processing tasks.

Age: We found that “early-exposed” bilingual adults (i.e.,
exposed to two languages before age 3, or the period
during which the brain exhibits its most exuberant neural
plasticity) process their two languages in highly similar
ways as monolinguals. These bilinguals utilize overlapping
classic language areas within the left hemisphere for each of
their languages, and, crucially, the same language areas
universally observed in monolinguals. Their bilingual brains
do not exhibit significant bilateral or distributed frontal
lobe activation. Interestingly, this overlapping dual language
processing is also mirrored in their equally high language
competence (low error rates) across their two languages
on classic behavioral language tasks during our fMRI
and/or fNIRS scanning. The areas of overlap include the
classic language areas such as Broca’s area, LIFC, and the
Bilingual and Monolingual Reading in Children

Our behavioral studies, crucial to educational neuroscience studies of bilingualism, now follow the young bilingual child into the early school years (ages 6–9 years, spanning grades 1, 2, and 3), to study the effects of having a bilingual child learn to read in two languages either at the same time—that is simultaneously—or first in one language and then later in their other language—that is sequentially. Specifically, “simultaneously” refers to “50/50 bilingual” instruction in two languages in relatively equal amounts during the school day throughout elementary school (e.g., Spanish and English through grades 1, 2, and 3), and “sequentially” refers to “90/10 bilingual” instruction, whereupon, initially, most of the instruction is conducted in the child’s dominant language (e.g., Spanish throughout grades 1, 2, and 3), with instruction in the new language (e.g., English) slowly increasing in amount throughout elementary school until it reaches approximately
50% Spanish and 50% English instruction in grade 5 (Berens, Kovelman, & Petitto, under revision). As throughout, we investigated how the age of first bilingual exposure and the type of reading instruction impact reading development in bilingual and monolingual children.

We found that the age of first bilingual language exposure has a strong impact on a young bilingual’s ability to achieve successful reading acquisition. In other words, there is most definitely a “sensitive period” for optimal bilingual language and reading exposure and mastery. Age of first bilingual exposure predicts how strong a reader a bilingual child can and will become in each of their two languages. Spanish–English bilingual children (in 50/50 bilingual programs) who were exposed to both of their two languages before age 3 had the best dual language reading performance as compared to their classmates who had later exposure by the time they were in grades 2–3. But we also observed ways that reading mastery in all young bilinguals could be improved, even involving those children who had bilingual language exposure at much older ages. Moreover, the type of bilingual instruction also had a significant impact: Most surprisingly, and most exciting regarding its educational policy implications, children from monolingual homes in bilingual schools were better readers than language/age-matched monolingual children in monolingual schools. For example, our results showed that children from monolingual English homes who were educated in a Bilingual English–Spanish 50/50 program performed better on phoneme awareness tasks—which are reading precursor tasks—than their peers educated in English-only programs. Other important reading advantages were also observed, for example, enhanced reading comprehension (for a complete report see Berens, Kovelman, & Petitto, submitted). Thus, these children were afforded reading advantages in select and important aspects of the reading process that are ultimately crucial to successful reading; in our lab, this is among our most exciting and telling findings, and may suggest the rather bold hypothesis that a monolingual child may be afforded particular educational advantages perhaps by simply being placed in bilingual schooling (Berens, Kovelman, & Petitto, 2009; Berens, Kovelman, and Petitto, submitted; Berens, Kovelman, Shalinksky, & Petitto, in preparation; Kovelman, Baker, & Petitto, 2008a).

Another encouraging benefit from the above studies on the impact of age of first bilingual language exposure on bilingual language and reading mastery is that they can serve as an important assessment tool (a yardstick) for teachers. Here, teachers can better situate the young bilingual reader developmentally relative to monolingual peers: Early exposed bilinguals can be expected to have reading performance comparable to that of monolinguals, whereas later-exposed bilinguals (ages 3–7) may have lower reading performance in their new language (relative to their home language) due largely to the incomplete acquisition of the new language and not because of a reading disability.

Finally, we also noted fascinating ways that different bilingual schooling affected our young Spanish–English bilinguals. Initially, 50/50 bilingual schooling advantaged the children’s processing of the underlying grammatical/structural components of reading, whereas 90/10 schooling advantaged the children’s surface phonetic analyses in reading. Keeping in mind that, over time, successful reading necessitates a movement away from a reliance on phonologically based components of letter-to-grapheme decoding to more abstract grammatical processing in reading, these particular findings have intriguing and important implications for bilingual educational policy.

Imaging the Brains of Bilingual and Monolingual Reading in Children

Following from our child bilingual reading studies, as well as our adult bilingual brain imaging studies, we wondered whether young bilingual children show any brain activation differences when reading words in each of their two languages. The answer is yes they do! In Berens, Kovelman, Dubins, Shalinksky, and Petitto (2009), we found that Spanish–English bilingual children’s brains reflect their acquisition of language-specific deep/English versus shallow/Spanish orthography. Here, we observed that there was greater recruitment of the right STG region during pseudoword reading, potentially reflecting more efficient sound-to-letter decoding strategies typical of alphabetic, shallow-language reading (Byrnes & Fox, 1998; Majerus et al., 2002; Norton, Kovelman, & Petitto, 2007; Tan, Laird, Li, & Fox, 2005). We also found increased bilateral Inferior Frontal activation in bilingual children, which may reflect the extra, dual lexical accessing demands associated with the IFC. These findings were consistent with the same observed with adult bilinguals, but here in young bilingual children, thereby providing support for “The Bilingual Signature” hypothesis (Kovelman, Baker, & Petitto, 2008b).

Summary

Overall, the above research bears directly on the nation’s educational priorities, policy, and practice regarding the education of bilingual children, especially “hold-back” views. In both behavioral and brain imaging studies, we found that the age of bilingual language exposure has a significant impact on children’s dual language mastery. Remarkably, early age bilingual exposure has a positive impact on multiple aspects of a child’s development: here, involving language and reading. Children who experience early, extensive, and systematic exposure to both of their languages quickly grasp the fundamentals of both of their languages and in a manner virtually identical to that of monolingual language learners. As adults, these bilingual individuals, in addition to their good
behavioral performance on language tasks, also show that
their brains are processing their two languages in a similar
manner, and virtually identical to monolingual adults. The field
raised concerns that early bilinguals may be linguistically,
cognitively and academically disadvantaged. Our findings
suggest that early bilingualism offers no disadvantages; on
the contrary, young bilinguals may be afforded a linguistic and
a reading advantage (for a theoretical account about the brain-
based mechanisms that may make possible early bilingual
and monolingual language acquisition, see Petitto, 2005).
Early dual language exposure is also key to skilled reading
acquisition. Moreover, learning to read in two languages may
afford an advantage to children from monolingual homes in
key phoneme awareness skills vital to reading success. Finally,
the brains of bilinguals are not deviant relative to monolingual
brains, and such findings support the educational benefits of
early and systematic dual language and reading exposure. Early
exposed bilinguals utilize overlapping classic language areas
within the left hemisphere for each of their languages, and
the same language areas universally observed in monolinguals.
Differential activation between bilingual and monolingual
brains may provide a new window into the language processing
potential not recruited in monolingual brains and reveal the
biological extent of the neural architecture underlying all
human language. Neural differences are further principled
and predictable based on the morphosyntactic differences
between the dual language structures and provide benefits to
the processing of each language.

Implications for Bilingual Education
Although the above work addresses one prevailing bilingual
myth that has affected educational policy—exposure to two
languages “too early” can cause developmental language delay
and confusion—it also addresses the flip-side of this myth:
Later exposure is better. Here, the view is that later exposure to
another language has little consequence on a child’s ability to
master the said language and thus the brain has little to do with
later-bilingual and second language learning. The reasoning is
that because we as adults can go out and take courses in, for
element, Japanese, and achieve fluent conversational skills,
without ostensibly no critical or sensitive period for second
language learning (as there is for first language learning). Given
this, and following this line of reasoning, it is therefore better
to provide a young child (say from a Spanish-speaking home)
with a strong linguistic and cognitive base first in the majority
language (e.g., English, holding back formal instruction in
Spanish) and, then, later, building on this solid foundation
in English, introduce the child to language study and reading
in her other language (e.g., Spanish). Although the premises
of this method are scientifically false, it could be said that it
is still better to embrace in our nation’s schools because it
is more sympathetic with the social reality of bilingualism.

In the real world, childhood bilingualism is not frequently
simultaneous and balanced, and normal population migration,
as well as sociopolitical conditions in the world, often causes
large groups of children from outside the language community
to enter schools at varying stages of life, even well into the
teenage years.

Bilingual language learning and reading indeed provide
complex educational challenges for today’s teachers and
schools. But what the above landscape of scientific discoveries
teaches us unequivocally is that the age of first bilingual
language exposure directly and seriously impacts children’s
ability to achieve linguistic fluency and reading in the new
(later-exposed) language, as well as the neural processing of
this newer language in the brain. “Hold-back” educational
policies that fly in the face of biology need not be so.

Our goal here was not to prescribe what should be done
for all young bilinguals, but instead to discover empirically
what are the most optimal learning conditions for bilingual
language mastery and what happens when life’s vagaries
prevent the most optimal conditions from occurring. What
we have discovered here is very positive and very encouraging.
We saw that while early dual language exposure is most
optimal to achieve highly proficient and equal dual language
mastery, children arriving late to a bilingual context can and
do achieve language competence in their new language. Key
here was our empirical discovery of the obligatory factors
required to achieve this outcome: Full mastery of the new
(later-exposed) language needs to occur in highly systematic
and multiple contexts that are richly varied involving both
home and community and, remarkably, cannot be achieved
through classroom instruction alone.

One final question that could be asked about the children
in our studies is whether there are individual differences such
that some children do not benefit from the simultaneous
bilingual language and reading exposure discussed within.
We saw no evidence of this. Even the children who performed
the “worst” in their bilingual group, nonetheless showed a
benefit from their bilingual education relative to the children
in traditional monolingual education groups in our studies
on the select language and reading tasks at hand. What was
especially powerful in this regard is that high SES and low SES
did not have an impact. In fact, as discussed within, bilingual
schooling appeared to ameliorate the deleterious impact on
reading and literacy classically associated in the literature
regarding low SES and reading and literacy skills (Berens
et al., 2009; Kovelman, Baker, & Petitto, 2008a). Our Ravens
test administered to all children (considered to be a nonverbal
index of intelligence) showed no differences between our
groups. Thus, it was not the case that high or low IQ, or high
or low SES children performed differently.

In general, the present findings, which now constitute a part
of the growing field of educational neuroscience, can teach our
educational institutions a lot: Young children from, say, a
Spanish-speaking home entering kindergarten, first grade, or the like, need not have Spanish withheld from them because of a fear that any exposure to Spanish in the schools will prohibit them from achieving fluency in English. These same children need not have Spanish books withheld from them because of a fear that any exposure to Spanish texts will prohibit their capacity to achieve successful reading in English. Teachers and parents need not fear using a Spanish word to a young child from a Spanish-speaking home (as a conceptual bridge) when teaching this child English. The November 5, 2002 public referendum banning bilingualism in the Commonwealth of Massachusetts need not have occurred.

Our next step is to identify and track the neural underpinnings of bilingual and monolingual language processing in babies from the age of 2 days. By doing so, this research will help adjudicate a classic scientific debate about whether language-specific versus perception-general mechanisms initiate/govern early language learning. This research will thus provide important answers to scientific questions about (a) the multiple factors that underlie early language acquisition and the specific type of processing tissue that underlie them, (b) the developmental trajectories of linguistic processing tissue, and (c) the peaked sensitivity that linguistic processing tissue has to certain kinds of linguistic input over other input in early development.

Our fNIRS studies will also yield guidelines for the principled use of fNIRS with infants that ultimately (after experimental replication/standardization) can have important diagnostic, remediation, and teaching utility in the following way. Our earlier studies had established that the STG, particularly the Planum Temporale (PT), is dedicated to processing specific rhythmically alternating patterns at the core of phonology in adults (e.g., Penhune, Cismaru, Dorsaint-Pierre, Petitto, & Zatorre, 2003; Petitto et al., 1997, 1998, 2000), with evidence that this is also true in infants as young as 3 months old (Holowka & Petitto, 2002) and 3 months (Petitto et al. 2004). Our present studies will evaluate whether this is true in much younger infants (from ages 2 days old). The scientific establishment of the neural tissue that underlies early phonological segmentation and processing, and its typical onset age in development, can ultimately be used (in combination with standardized fNIRS data from typically developing babies) to identify and predict babies at risk for language and phonological sequencing disorders (e.g., dyslexia) in very early life, indeed even before they babble or utter their first words (Shaywitz et al., 1998). By doing so, we will also provide a new way to distinguish between deviance and delay in children’s phonological processing in bilingual and monolingual children. These findings about children’s phonological capacity will thus provide scientific evidence-based information vital to word segmentation at the core of successful language learning and reading and will affect educational policy regarding early language remediation and teaching. To be sure, we hope for this research to continue to yield advances that have great potential to affect education policy and practice, including those that will change our understanding of childhood bilingualism—indeed, all human language processing.

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REFERENCES


Berens, M. S., Kovelman, I., & Petitto, L. A. (under revision). Teaching reading in two languages: Should we teach both languages at the same time or in sequence? Language Learning Journal.


Brer, J. (2003). At the current time, might it be better to encourage research in NeuroLearning (a basic science) rather than NeuroEducation (an applied science)? Published abstracts of the session commemorating the 400th anniversary of the Foundation of the Pontifical Academy of Sciences. Vatican City: Pontifical Academy of Sciences.


the International Workshop on Near-Infrared Spectroscopy, Cambridge, MA. 


