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 comapred 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 is 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

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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 mylenization (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 myelinization 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 ($\sim$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 Peña et al., 2003).

Fascinating brain changes were seen over early life dependent 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, & Pfiefer, 2002; Frenck-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 Bleser 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) *age* 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 5, 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

STG (Kovelman et al., 2009; Kovelman, Shalinsky, Berens, White, & Petitto, Revise & Resubmit); this finding has been corroborated in other bilingual brain scanning studies (Kim et al., 1997; Wartenburger et al., 2003; Weber-Fox & Neville, 1999). However, "*later-exposed*" bilinguals exhibit more *bilateral* activation, recruit more distributed frontal lobe tissue (including working memory and inhibitory areas) and frequently exhibit more cognitive effort as measured in analyses of their greater errors on the language behavioral tasks during scanning (Kim et al., 1997; Wartenburger et al., 2003; Weber-Fox & Neville; Perani et al., 1996). Thus, the age that a person is exposed to two languages does have a serious impact on the human brain. Maturational indices of the human brain indeed mediate bilingual language acquisition: *Later*-bilingual exposure does *change* the typical pattern of the brain's neural organization for language processing, but early bilingual exposure does not.

Bilingual and monolingual brains compared: An important difference between bilingual and monolingual brains was that bilinguals had a significantly greater increase in the blood oxygenation level-dependent signal in the LIFC (BA 45) when processing English than the English monolinguals. The results provide insight into the decades-old question about the degree of separation of bilinguals' dual language representation. The differential activation for bilinguals and monolinguals opens the question as to whether there may possibly be a "neural signature" of bilingualism. Differential activation may further provide a fascinating window into the language processing potential *not* recruited in monolingual brains. It further shows the biological extent of the neural architecture underlying all human language (Kovelman, Shalinsky, Berens, & Petitto, 2008; Shalinsky, Kovelman, Berens, & Petitto, 2006; we also found strikingly similar cross-linguistic, cross-modal results in hearing Sign-Speech bilingualse; see Kovelman, Shalinsky, White et al., 2008).

Differences in linguistic structure: We also found that highly proficient and early-exposed adult Spanish–English bilinguals, who completed a syntactic "sentence judgment task" in English only and then separately in Spanish only, showed neural differences in principled and predictable ways based on the morphosyntactic differences between Spanish and English (Kovelman, Baker, & Petitto, 2008b; tasks provided by Caplan, Alpert, & Waters, 1998).

Previous neuroimaging studies have shown that English monolinguals have higher LIFC (BA 44/45) activation for the more complex ("harder") SO sentence syntax in English rather than for the less complex ("easier") OS relative clause sentences in English (Caplan, 2001; Caplan et al., 1998; Stromswold, Caplan, Alpert, & Rauch, 1996), which was also observed in our Spanish–English bilinguals when processing in English only and our monolingual English participants processing in English. Remarkably, and appropriately so, this was not observed when the Spanish–English bilinguals were processing Spanish sentences. In Spanish, a romance language where monolingual speakers make heavier reliance on verb morphology than word order when judging a relative clause sentence (Bates, Devescovi, & D'Amico, 1999), one would expect no differences in brain activity between the two sentence types with varying word order. This is exactly what we observed in our bilinguals in Spanish. As such, in our participants, their bilingual brains honored the grammatical distinction between their two languages. Thus, early bilinguals with extensive dual language exposure develop predominantly differentiated representations for each of their languages in one brain.

In returning to the crucial topic of the age of first bilingual language exposure and its impact on the developing brain and optimal dual language mastery, we consider the construct of the "critical or sensitive period" hypothesis. In the search to discover whether there is a "critical or sensitive period" (Lenneberg, 1967) for later-exposed bilingual or second language learning, scientists had first conducted *behavioral* experiments on bilinguals' language *proficiency*, as a function of whether they were introduced to their other language earlier versus later in life. These behavioral studies consistently found that proficiency in the later-exposed bilingual and/or second language learners declined dramatically if learned after puberty, and not earlier (Johnson & Newport, 1989; McDonald, 2000). The present generation of cognitive neuroscience studies of the neural underpinnings of language processing in early versus late bilingual language learners provides clarification of the brain's mechanisms underlying these now classic psycholinguistic findings. In addition, the above findings on phonological processing, which is important to successful reading mastery, have led to the following generation of studies regarding how bilingual and monolingual children and adults read.

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 throughout 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, Shalinksy, & 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 example, Japanese, and achieve fluent conversational skills, there is 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, can*not* 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 5 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

August, D., Carlo, M., Dressier, C., & Snow, C. (2005). The critical role of vocabulary development for English language learners. *Learning Disabilities Research & Practice*, *20*, 50–57.

August, D., & Shanahan, T. (2006). *Developing literacy in second-language learners: Report of the national literacy panel on language*. Hillsdale, NJ: Erlbaum.

Baker, S. A., Idsardi, W. J., Golinkoff, R., & Petitto, L. A. (2005). The perception of [phonetic] handshapes in American Sign Language. *Memory & Cognition*, *33*, 887–904.

Baker, S. A., Michnick-Golinkoff, R., & Petitto, L. A. (2006). New insights into old puzzles from infants' categorical discrimination of soundless phonetic units. *Language Learning and Development*, *2*, 147–162.

Baker, S. A., Sootsman, J. L., Petitto, L. A., & Golinkoff, R. (2003, April). Hearing four-month-olds'perception of handshapes in American Sign Language: No experience required. Poster presented at the Society for Research in Child Development biennial meeting, Tampa, FL.

Bates, E., Devescovi, A., & D'Amico, S. (1999). Processing complex sentences: A cross-linguistic study. *Language Cognitive Processes*, *14*, 69–123.

Berens, M. S., Kovelman, I., Dubins, M., Shalinksky, M. H., & Petitto, L. A. (2009, March). Shedding new light on reading in bilingual and monolingual children. Poster presented at Cognitive Neuroscience Society Meeting, San Francisco, CA.

Berens, M. S., Kovelman, I., & Petitto, L. A. (2009, April). Comparing two-way bilingual instruction programs: is it best to teach reading in both languages at the same time or in sequence? Poster presented at Biennial Society for Research in Child Development, Denver, CO.

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.

Berens, M. S., Kovelman, I., Shalinsky, M. H., & Petitto, L. A. (In Preparation). Shining light on Bilingual and Monolingual children's reading in two languages: A Near Infrared Spectroscopy investigation. Target: *Nature Neuroscience*.

Bruer, J. (1998). The brain and child development: Time for some critical thinking. *Public Health Reports*, *113*, 388–397.

Bruer, J. (2002). Avoiding the pediatrician's error: How neuroscientists can help educators (and themselves). *Nature Neuroscience*, *5*, 1031–1033.

Bruer, 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.

Burns, T. C., Werker, J. F., & McVie, K. (2003). Development of phonetic categories in infants raised in bilingual and monolingual environments. In B. Beachley, A. Brown, & F. Conlin (Eds.), *Proceedings of the 27th annual Boston University Conference on Language Development*. Somerville, MA: Cascadilla Press.

Byrnes, J. P., & Fox, N. A. (1998). The educational relevance of research in cognitive neuroscience. *Educational Psychology Review*, *10*, 297–342.

Caplan, D. (2001). Functional neuroimaging studies of syntactic processing. *Journal of Psycholinguist Research*, *30*, 297–320.

Caplan D., Alpert, N., & Waters, G. (1998) Effects of syntactic structure and propositional number on patterns of regional cerebral blood flow. *Journal of Cognitive Neuroscience*, *10*, 541–552

Chee, M. W., Soon, C. S., Lee, H. L., & Pallier, C. (2004). Left insula activation: A marker for language attainment in bilinguals. *Proceedings of the National Academy of Sciences, U.S.A.*, *101*, 15265–15270.

Cohen, L. B. (1972). Attention-getting and attention-holding processes of infant visual preferences. *Child Development*, *43*, 869–879.

Crawford, J. (1999). *Bilingual education: history, politics, theory, and practice*. Los Angeles: Bilingual Education Services.

De Bleser, R., Dupont, P., Postler, J., Bormans, G., Speelman, D., Mortelmans, L., et al. (2003). The organization of the bilingual lexicon: A PET study. *Journal of Neurolinguistics*, *16*, 439–456.

Dehaene, S., Dupoux, E., Mehler, J., Cohen, L., Paulesu, E., Perani, D., et al. (1997). Anatomical variability in the cortical representation of first and second language. *NeuroReport*, *8*, 3809–3815.

Dubins, M., Berens, M. S., Kovelman, I., Shalinsky, M. H., & Petitto, L. A. (2009, March). An oddball investigation of monolingual and bilingual infants' phonetic discriminatoin using functional near-infrared spectroscopy (fNIRS). Poster presented at the Annual Meeting of the Cognitive Neuroscience Society, San Francisco, CA.

Dubins, M. H., Berens, M. S., Kovelman, I., Shalinsky, M. H., & Petitto, L. A. (In preparation). An Investigation of Early Phonetic Processing in Monolingual and Bilingual Infants Using New Functional Near-Infrared Spectroscopy (fNIRS).

Dubins, M., White, K., Berens, M. S., Kovelman, I., Shalinsky, M. H., & Petitto, L. A. (2009, April). The neural basis of infant linguistic and non-linguistic sound processing seen through the new light of fNIRS. Poster presented at the Biennial Society for Research in Child Development conference, Denver, CO.

Dubins, M. H., White, K. S., Berens, M. S., Kovelman, I., Shalinksky, M. H., & Petitto, L.A. (In preparation). The Neural Basis of Infant Linguistic and Non-Linguistic Sound Processing Seen Through the New Light of fNIRS.

Frenck-Mestre, C., Anton, J. L., Roth, M., Vaid, J., & Viallet, F. (2005). Articulation in early and late bilinguals' two languages: Evidence from functional magnetic resonance imaging. *NeuroReport*, *16*, 761–765.

Friederici, A. D., Steinhauer, K., & Pfiefer, E. (2002). Brain signatures of artificial language processing: evidence challenging the critical period hypothesis. *Proceedings of the National Academy of Sciences, U.S.A.*, *99*, 529–534.

Geake, J. G. (2003). Adapting middle level educational practices to current research on brain functioning. *Journal of the New England League of Middle Schools*, *15*(2), 6–12.

Geake, J. G., & Cooper, P. W. (2003). Implications of cognitive neuroscience for education. *Westminster Studies in Education*, *26*, 7–20.

Genesee, F. (1989). Early bilingual development: one language or two? *Journal of Child Language*, *6*, 161–179.

Genesee, F., Nicoladis, E., & Paradis, J. (1995). Language differentiation in early bilingual development. *Journal of Child Language*, *22*, 611–631.

Goswami, U. (2004). Neuroscience and education. *British Journal of Educational Psychology*, *74*(1), 1–14.

Grosjean, F. (Ed.). (2001). *The bilingual's language modes*. Malden, MA: Blackwell.

Hai Tan, L., Laired, A. R., Li, K., & Fox, P. T. (2005). Neuranatomical correlates of phonological processing of chinese characters and alphabetic words: A meta-analysis. *Human Brain Mapping*, *25*, 83–91.

Hernandez, A. E., Martinez, A., & Kohnert, K. (2000). In search of the language switch: An fMRI study of picture naming in Spanish–English bilinguals. *Brain and Language*, *73*, 421–431.

Holowka, S., & Petitto, L. A. (2002). Left hemisphere cerebral specialization for babies while babbling. *Science*, *297*(5586), 1515.

Holowka, S., Brosseau-Lapré, F., & Petitto, L. A. (2002). Semantic and conceptual knowledge underlying bilingual babies' first signs and words. *Language Learning*, *52*, 205–262.

Ito, M. (2004). Nurturing the brain' as an emerging research field involving child neurology. *Brain Development*, *26*, 429–433.

Johnson, J. S., & Newport, E. L. (1989). Critical period effects in second language learning: the influence of maturational state on the acquisition of English as a second language. *CognitivePsychology*, *21*, 60–99.

Jusczyk, P. W. (1997). *The discovery of spoken language*. Cambridge, MA: MIT Press.

Kim, K. H., Relkin, N. R., Lee, K. -M., & Hirsch, J. (1997). Distinct cortical areas associated with native and second languages. *Nature*, *388*, 171–174.

Klein, D., Watkins, K. E., Zatorre, R. J., & Milner, B. (2006). Word and nonword repetition in bilingual subjects: a PET study. *Human Brain Mapping*, *27*, 153–161.

Kovelman, I., Baker, S. A., & Petitto, L. A. (2008a). Age of first bilingual language exposure as a new window into bilingual reading development. *Bilingualism: Language and Cognition*, *11*, 203–223.

Kovelman, I., Baker, S. A., & Petitto, L. A. (2008b). Bilingual and Monolingual brains compared: An fMRI investigation of syntactic processing and a possible "neural signature" of bilingualism. *Journal of Cognitive Neuroscience*, *20*(1), 153–169.

Kovelman, I., Berens, M. S., & Petitto, L. A. (2006, May). Teaching reading to young bilinguals: is whole word or phonics the answer? Presented at biannual Language Acquisition and Bilingualism: Consequences for a Multilingual Society, Toronto, Ontario.

Kovelman, I., Berens, M. S., & Petitto, L. A. (In preparation). Phonics versus Whole-word reading approaches with bilingual children: Which is best?

Kovelman, I., & Petitto L. A. (2002, November). Bilingual babies' maturational and linguistic milestones as a function of their age of first exposure to two languages. Poster presented at the conference for the Society for Neuroscience, Orlando, FL.

Kovelman, I., & Petitto, L. A. (2003, April). States of language development in bilingual children exposed to their other language at different ages. Poster presented at the International Symposium on Bilingualism, Phoenix, AZ.

Kovelman, I., Shalinsky, M. H., Berens, M. S., & Petitto, L. A. (2008). Shining light on the brain's "Bilingual Signature∼:" a functional near infrared spectroscopy investigation of semantic processing. *NeuroImage*, *39*(1), 1457–1471.

Kovelman, I., Shalinsky, M. H., Berens, M. S., White, K., & Petitto, L. A. (Revise & Resubmit). New fNIRS brain imaging investigation of lexical repetition in sign-speech bimodal bilinguals. *Brain Research*.

Kovelman, I., Shalinsky, M., White, K., Schmitt, S. N., Berens, M. S., & Petitto, L. A (2008). fNIRS brain imaging investigation of bilingualism: A new view from sign-speech bimodal bilinguals. Presented at the Annual Meeting of the Cognitive Neuroscience Society Conference, San Francisco, CA.

Kovelman, I., Shalinsky, M. H., White, K., Schmitt, S. N., Berens, M. S., Paymer, N., et al. (2009). New light on language switching form sign-speech bimodal bilinguals using fNIRS brain-imaging. *Brain & Language*.

Kuhl, P. K., & Padden, D. M. (1983). Enhanced discriminability at the phonetic boundaries for the place feature in macaques. *Journal of the Acoustical Society of America*, *73*, 1003–1010.

Lanza, E. (1992). Can bilingual two-year-olds code-switch? *Journal of Child Language*, *19*, 633–658.

Lenneberg, E. H. (1967). *Biological foundations of language*. New York: Wiley.

Lesaux, N. K., Koda, K., Siegel, L. S., & Shanahan, T. (2006). *Development of literacy*. Mahwah, NJ: Erlbaum.

Lipka, O., Lesaux, N. K., & Siegel, L. S. (2006). Retrospective analyses of the reading development of grade 4 students with reading disabilities: Risk status and profiles over 5 years. *Jornal of Learning Disabilities*, *39*, 364–378.

Mahendra, N., Plante, E., Magloire, J., Milman, L., & Trouard, T. P. (2003). fMRI variability and the localization of languages in the bilingual brain. *NeuroReport*, *14*, 1225–1228.

Majerus, S., Belayachi, S., De Smedt, B., Leclercq, A. L., Martinez, T., Schmidt, C., et al. (2008). Neural networks for short-term memory for order differentiate high and low proficiency bilinguals. *Neuroimage*, *42*, 1698–1713.

Majerus, S., Collette, F., Van der Linden, M., Peigneux, P., Laureys, S., Delfiore, G., et al. (2002). A PET investigation of lexicality and phonotactic frequency in oral language processing. *Cognitive Neuropsychology*, *19*, 343–361.

Marian, V., Spivey, M., & Hirsch, J. (2003). Shared and separate systems in bilingual language processing: Converging evidence from eyetracking and brain imaging. *Brain and Language*, *86*, 70–82.

McDonald, J. L. (2000). Grammaticality judgments in a second language: influences of age acquisition and native language. *Applied Psycholinguistics*, *21*, 395–423.

Meisel, J. M. (1989). Early differentiation of languages in bilingual children. In K. Hyltenstam & L. Obler (Eds.), *Bilingualism across the lifespan: Aspects of acquisition, maturity and loss* (pp. 13–40). Cambridge, UK: Cambridge University Press.

Meisel, J. M. (2000). Early differentiation of languages in bilingual children. In L. Wei (Ed.), *The bilingualism reader* (pp. 344–369). London: Routledge.

Norton, E., Baker, S., & Petitto, L. A. (2003, July). Bilingual infants' perception of handshapes in American Sign Language. Poster presented at the University of Pennsylvania Institute for Research in Cognitive Science summer workshop, Philadelphia, PA.

Norton, E. S., Kovelman, I., & Petitto, L. A. (2007). Are there separate neural systems for spelling? New insights into the role of rules and memory in spelling from fMRI. *International Journal of Mind, Brain and Education*, *1*(1), 48–59.

O'Boyle, M. W., & Gill, H. S. (1998). On the relevance of research findings in cognitive neuroscience to educational practice. *Educational Psychology Review*, *10*, 397–400.

Paradis, M. (1997). The cognitive neuropsychology of bilingualism. In A. M. B. de Groot (Ed.), *Tutorials in bilingualism: psycholinguistic perspectives* (pp. 331–354). Mahwah, Nj: Erlbaum.

Peña, M., Maki, A., Kovacic, D., Dehaene-Lambertz, G., Koizumi, H., Bouquet, F., et al. (2003). Sounds and silence: An optical topography study of language recognition at birth. *Proceedings of the National Academy of Sciences*, *100*, 11702–11705.

Penhune, V. B., Cismaru, R., Dorsaint-Pierre, R., Petitto, L. A., & Zatorre, R. J. (2003). The morphometry of auditory cortex in the congenitally deaf measured using MRI. *NeuroImage*, *20*, 1215–1225.

Perani, D., Dehaene, S., Grassi, F., Cohen, L., Cappa, S. F., Dupoux, E., et al. (1996). Brain processing of native and foreign languages. *Neuroreport*, *7*, 2439–2444.

Perani, D., Abutalebi, J., Paulesu, E., Brambati, S., Scifo, P., Cappa, S. F., et al. (2003). The role of age of acquisition and language usage in early, high-proficient bilinguals: An fMRI study during verbal f luency. *Human Brain Mapping*, *19*, 170–182.

Petitto, L. A. (2003). Revolutions in brain, language and education. *Published abstracts of thesession commemorating the 400th anniversary of the Foundation of the Pontifical Academy of Sciences*. Vatican City: Pontifical Academy of Sciences.

Petitto, L. A. (2005). How the brain begets language: on the neural tissue underlying human language acquisition. In J. McGilvray (Ed.), *The Cambridge companion to Chomsky* (pp. 84–101). Cambridge, UK: Cambridge University Press.

Petitto, L. A. (2007). Cortical images of early language and phonetic development using Near Infrared Spectroscopy. In K. Fischer & A. Battro (Eds.), *The educated brain* (pp. 213–232) Cambridge, UK: Cambridge University Press,.

Petitto, L. A., Baker, S., Baird, A., Kovelman, I., & Norton, E. (2004, February). Near-infrared spectroscopy studies of children and adults during language processing.Poster presented at the International Workshop on Near-Infrared Spectroscopy, Cambridge, MA.

Petitto, L. A., & Dunbar, K. N. (2004). New findings from educational neuroscience on bilingual brains, scientific brains, and the educated mind. *Monograph: Mind, Brain and Education.* Cambridge, MA: Harvard University, Graduate School of Education.

Petitto, L. A., & Holowka, S. (2002) Evaluating attributions of delay and confusion in young bilinguals: Special insights from infants acquiring a signed and a spoken language. *Sign Language Studies*, *3*(1), 4–33.

Petitto, L. A., Holowka, S., Sergio, L. E., & Ostry, D. (2001a). Language rhythms in baby hand movements. *Nature*, *413*, 35–36.

Petitto, L. A., Katerelos, M., Levy, B. G., Gauna, K., Tetreault, K., & Ferraro, V. (2001b). Bilingual signed and spoken language acquisition from birth: Implications for the mechanisms underlying early bilingual language acquisition. *Journal of Child Language*, *28*, 453–496.

Petitto, L. A., & Kovelman, I. (2003). The bilingual paradox: How signing-speaking bilingual children help us to resolve it and teach us about the brain's mechanisms underlying all language acquisition. *Learning Languages*, *8*(3), 5–19.

Petitto, L. A., Kovelman, I., & Harasymowycz, U. (2003). Bilingual language development: Does learning the new damage the old? Abstracts of the Society for Research in Child Development, Tampa, FL.

Petitto, L. A., & Marentette, P. (1991). Babbling in the manual mode: Evidence for the ontogeny of language. *Science*, *251*, 1483–1496.

Petitto, L. A., Zatorre, R. J., Gauna, K., Nikelski, E. J., Dostie, D., & Evans, A. C. (2000). Speech-like cerebral activity in profoundly deaf people while processing signed languages: Implications for the neural basis of all human language. *Proceedings of the National Academy of Sciences*, *97*, 13961–13966.

Petitto, L. A., Zatorre, R. J., Nikelski, E. J., Gauna, K., Dostie, D., & Evans, A. C. (1997). Cerebral organization for language in the absence of sound: A PET study of deaf signers processing signed languages. Published abstracts of the 27th annual meeting of the Society for Neuroscience, 2228.

Petitto, L. A., Zatorre, R. J., Nikelski, E. J., Gauna, K., Dostie, D., & Evans, A. C. (1998). By hand or by tongue: Common cerebral blood flow activation during language processing in signed and spoken languages. *NeuroImage*, *7*(4), 193.

Price, C. J., Green, D. W., & von Studnitz, R. (1999). A functional imaging study of translation and language switching. *Brain*, *122*, 2221–2235.

Redlinger, W., & Park, T. Z. (1980). Language mixing in young bilingual children. *Journal of Child Language*, *7*, 337–352.

Rodriguez-Fornells, A., Rotte, M., Heinze, H. J., Noesselt, T., & Muente, T. F. (2002). Brain potential and functional MRI evidence for how to handle two languages with one brain. *Nature*, *415*, 1026–1029.

Rodriguez-Fornells, A., van der Lugt, A., Rotte, M., Britti, B., Heinze, H. J., & Munte, T. F. (2005). Second language interferes with word production in f luent bilinguals: Brain potential and functional imaging evidence. *Journal of Cognitive Neuroscience*, *17*, 422–433.

Shalinsky, M. H., Kovelman, I., Berens, M. S., & Petitto, L. A. (2006, October). Near-infrared spectroscopy: Shedding light on the neurological signature of bilingualism. Presented at annual Society for Neuroscience conference, Atlanta, GA.

Shaywitz, S., Shaywitz, B., Pugh, K., Fulbright, R., Constable, R., Mencl, W., et al. (1998). Functional disruption in the organization of the brain for reading in dyslexia. *Proceedings of the National Academy of Sciences*, *95*, 2636–2641.

Stromswold, K., Caplan, D., Alpert, N., & Rauch, S. (1996). Localization of syntactic comprehension by positron emission tomography. *Brain and Language*, *52*, 452–473.

Vihman, M. (1985). Language differentiation by the bilingual infant. *Journal of Child Language*, *12*, 297–324.

Volterra, V., & Taeschner, T. (1978). The acquisition and development of language by bilingual children. *Journal of Child Language*, *5*, 311–326.

Wartenburger, I., Heekeren, H. R., Abutalebi, J., Cappa, S. F., Villringer, A., & Perani, D. (2003). Early setting of grammatical processing in the bilingual brain. *Neuron*, *37*(1), 159–170.

Weber-Fox, C. M., & Neville, H. J. (1996). Maturational constraints on functional specializations for language processing: ERP and behavioral evidence in bilingual speakers. *Journal of Cognitive Neuroscience*, *8*, 231–256.

Weber-Fox, C., & Neville, H. J. (1999). Functional neural subsystems are differentially affected by delays in second-language immersion: ERP and behavioral evidence in bilingual speakers. In D. Birdsong (Ed.), *New perspectives on the critical period for second language acquisition* (pp. 23–38). Hillsdale, NJ: Erlbaum.

Weber-Fox, C. M., & Neville, H. J. (2001). Sensitive periods differentiate processing of open- and closed-class words: An ERP study of bilinguals. *Journal of Speech, Language, and Hearing Research*, *44*, 1338–1353.

Werker, J. F., & Tees, R. C. (1983). Developmental changes across childhood in the perception of non-native speech sounds. *Canadian Journal of Psychology*, *37*, 278–286.

White, K., Kovelman, I., Shalinsky, M., Petitto, L. A., Berens, M. S., Dubins, M. (2008). The neural basis of infant phonological processing seen through the new light of fNIRS. Presented at the Annual Cognitive Neuroscience Society conference. San Francisco, CA.