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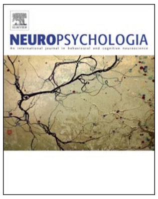

Bilingualism yields language-specific plasticity in left hemisphere's circuitry for learning to read in young children

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ABSTRACT

How does bilingual exposure impact children's neural circuitry for learning to read? Theories of bilingualism suggests that exposure to two languages may yield a functional and neuroanatomical adaptation to support the learning of two languages (Klein et al., 2014). To test the hypothesis that this neural adaptation may vary as a function of structural and orthographic characteristics of bilinguals' two languages, we compared Spanish-English and French-English bilingual children, and English monolingual children, using functional Near Infrared Spectroscopy neuroimaging (fNIRS, ages 6–10, N =26). Spanish offers consistent sound-to-print correspondences ("phonologically transparent" or "shallow"); such correspondences are more opaque in French and even more opaque in English (which has both transparent and "phonologically opaque" or "deep" correspondences). Consistent with our hypothesis, both French- and Spanish-English bilinguals showed hyperactivation in left posterior temporal regions associated with direct sound-to-print phonological analyses and hypoactivation in left frontal regions associated with assembled phonology analyses. Spanish, but not French, bilinguals showed a similar effect when reading Irregular words. The findings inform theories of bilingual and cross-linguistic literacy acquisition by suggesting that structural characteristics of bilinguals' two languages and their orthographies have a significant impact on children's neuro-cognitive architecture for learning to read.

1. Introduction

How does a bilingual child learn to read in two different languages? Children who receive early and systematic exposure to two languages achieve high proficiency in each language (Jasińska and Petitto, 2013, 2014; Kovelman et al., 2008a; Neville, 1993; Petitto et al., 2012; Weber-Fox and Neville, 1996). Neuroimaging evidence suggests that such early and systematic bilingual exposure may result in a "neural signature" of bilingualism, or experience-driven changes in neural activation supporting learning two languages (Jasińska and Petitto, 2013, 2014; Kovelman et al., 2008b, 2008c); that is, bilingual acquisition should yield quintessentially "bilingual" rather than "monolingual" outcomes (Grosjean, 1989). A bilingual child's two languages are well known to interact with each other during acquisition (Kroll et al., 2008), and structural characteristics of the two languages and orthographies could impact how a bilingual child learns to read and a child's brain organization for reading. To test this hypothesis, we compared French-English and Spanish-English bilingual children to English monolingual children to examine how bilingual exposure across different languages (Spanish and French) impacts children's English reading performance and underlying neural activation patterns.

Literacy acquisition research has now extensively mapped both the linguistic and cognitive skills, and their corresponding neural networks, that underlie learning to read in young monolingual readers of English and many other languages (McNorgan et al., 2011; Perfetti et al., 2006, 2007; Pugh et al., 2001; Sandak et al., 2004). Three key findings have emerged. First, learning to map language sounds (phonology) onto orthographic representations (e.g., letters) is foundational for learning to read across all orthographies (Ho and Bryant, 1997; Ziegler and Goswami, 2005). Second, improvement in this ability is supported by changes in the functionality and interconnections between left inferior frontal, temporo-parietal and occipito-temporal

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regions for language analyses and mapping linguistic representations onto print (Hoeft et al., 2007; Pugh et al., 2001). Third, orthographic experiences can leave a language-specific impact on individuals' brain organization for reading (Perfetti, et al., 2013).

For proficient readers, word knowledge is comprised of tightly interconnected units of sound, meaning and orthography (Perfetti and Hart, 2002; Perfetti et al., 2006, 2007). Reading primarily consists of processes distributed over these levels of linguistic representation (phonology, semantics, orthography), according to contemporary computational models of reading, known collectively as "triangle models of reading" (Boukrina and Graves, 2013; Harm and Seidenberg, 2004; Hoffman et al., 2015; Rueckl, 2016). To decode a word and access its meaning, orthographic representations activate corresponding phonological and semantic networks. Mapping phonemes to graphemes is an important step in learning to read (Liberman et al., 1989). Skilled reading involves this connection among orthography-phonology-semantic (whereby access to semantic representations is mediated by phonological representation), as well as a direct orthography-semantic connection (whereby, semantic representations are directly retrieved based on orthographic structure). The division of labor among these pathways changes over development, however, all connections remain crucial to skilled word identification (Harm and Seidenberg, 1999, 2004). With increased reading experience and skill, readers may rely to an increasing degree on direct associations between orthography and semantics (Share, 1995), through print-meaning or orthography-semantic mapping, also referred to as the *lexical route* (Harm and Seidenberg, 2004; Plaut et al., 1996; Seidenberg and McClelland, 1989).

Languages vary in the regularity with which phonological units map onto print. Languages that have a direct one-to-one mapping between sound and print are *transparent orthographies*; these include, for example, Spanish and Finnish. On the other hand, languages that have irregular mapping between sound and print are *opaque orthographies*; these include, for example, English, and logographic languages such as Chinese. The word "dog" is an example of regular or transparent sound-to-print mapping and the word "neighbor" is an example of irregular or opaque sound-to-print mapping. These differences have consequences for learning to read (Ziegler and Goswami, 2005). According to the orthographic depth hypothesis, readers of transparent orthographies rely to a greater extent on the orthography-phonology-semantic pathway as compared with readers of opaque orthographies, who rely to a greater extent on the orthography-semantic pathway (Frost et al., 1987). For example, a comparison of reading development across five languages (from transparent to opaque: Finnish, Hungarian, Dutch, Portuguese, and French) found differences in reading performance modulated by orthographic transparency (Ziegler et al., 2010). Phonological awareness was a robust universal predictor of reading outcomes in the sample of 1,265 Grade 2 children (~8 years old), however, the contribution of phonology to reading was more robust for transparent versus opaque orthographies (Ziegler et al., 2010). Therefore, for a young beginning reader of Finnish, phonological awareness has a more robust role in reading than for a young beginning reader of French.

Orthographic differences also have consequences for the extent to which readers engage left frontal regions that support complex sound-to-print assembly versus posterior-temporal regions that help integrate orthographic, phonological, and lexico-semantic rules (Das et al., 2011; Jamal et al., 2012). The temporo-parietal system, including the angular and supramarginal gyrus, is involved in lexical-semantic processing and has an important role in converting orthography into phonology (Moore and Price, 1999). The left superior temporal gyrus (STG, BA 21/22/42) is important in phonological processing (e.g., Petitto et al., 2000; Zatorre and Belin, 2001). The anterior reading system includes the left inferior frontal gyrus (LIFG); the more posterior portion is involved in sublexical phonological coding, phonological memory, and syntactic processing (Pugh et al., 2001) and the more anterior portion is involved in lexical access and semantic retrieval (Poldrack et al., 1999). This architecture for reading is part of a larger cortical network supporting language and other cognitive functions, and is adapted to the task of reading. For example, the LIFG is involved other aspects of language processing, such as articulatory motor planning (Davis et al., 2008).

For instance, a comparison between adult monolingual readers of English and Italian during a pseudoword reading task revealed that English readers showed stronger activation of left inferior frontal regions – associated with lexical access, while Italian readers showed stronger activations in left superior temporal regions – associated with phonological processing (Paulesu et al., 2000). How then might early-life exposure to both a phonologically-transparent and a phonologically-opaque language impact bilingual children's neural architecture for reading?

Newly-emerging research suggests that early bilingual exposure might change the manner in which young bilingual learners form the interconnections between phonology, meaning, and orthography. Importantly, the impact of bilingual exposure is thought to extend beyond individual literacy skills and impact the underlying architecture of children's emergent literacy (Proctor et al., 2006; Uchikoshi, 2012). Theories of bilingual language processing suggest that even when using only one of their languages, bilinguals have access to linguistic and orthographic representations of their other language (Kroll et al., 2008). Such tight interaction between bilinguals' two languages facilitates the sharing or "transfer" of literacy knowledge gained in one language towards learning to read in another language, bidirectionally (Proctor et al., 2010). For instance, several studies comparing Spanish-English or Italian-English bilinguals to English monolinguals revealed that bilingual learners relied more heavily on phonology to read words (Kremin et al., 2016) and/or outperformed English monolinguals on English phonological literacy tasks (D'Angiulli et al., 2001; Kovelman et al., 2008a), suggesting that literacy skills gained in a phonologically-transparent orthography (Italian, Spanish) can transfer towards learning to read in a more opaque orthography (English). On the other hand, Chinese-English bilinguals might weigh more heavily on meaning-to-print interconnections for learning to read in English, as compared to English monolinguals, whereas Spanish-English bilinguals might weigh more heavily on sound-to-print interconnections for learning to read (Hsu et al., 2016; Ip et al., 2016).

The lion's share of developmental bilingual literacy research has been conducted with bilingual adults who either learned two languages at the same time or sequentially during childhood (e.g., Abutalebi et al., 2013; Berken et al., 2015). The findings generally suggest that for sequential bilingual learners, there is an impact of first language exposure on their second language processing. For instance, studies by Tan et al. (2003) and Das et al. (2011) investigated bilinguals who learned to read in either Chinese or Hindi first, and English second (relative to English, Chinese is more phonologically-opaque and Hindi is more phonologically-transparent). As compared to English monolinguals, Chinese-English bilinguals showed greater activation in left frontal regions associated with mnemonic and analytical demands for complex sound-to-print mappings (Tan et al., 2003). By contrast, as compared to English monolinguals, Hindi-English bilinguals showed greater activation in left temporo-parietal regions associated with more direct sound-to-print mappings (Das et al., 2011).

Nevertheless, these data also raise the question of whether early and systematic bilingual experiences yield changes in neurodevelopmental patterns of activation for reading (Jasińska and Petitto, 2013; Kovelman et al., 2008a). Unfortunately, little is known about the brain bases of bilingual literacy during the early periods when children establish the basic literacy skills (Hernandez et al., 2015), especially in relation to bilingual speakers of different languages and monolinguals. Therefore, to shed light on the possible impact of dual language exposure on children's neural architecture for learning to read, we compared young Spanish-English and French-English bilinguals to

English monolinguals. Here we take this inquiry one step further and ask whether structural characteristics of bilinguals' two languages (transparent versus opaque orthography) make a significant impact on children's *neural* architecture of learning to read.

1.1. Hypotheses and predictions

First, we hypothesized that bilingual exposure to a language that places greater emphases on sound-to-print associations (Spanish) would impact the functional activation of brain regions associated with phonological processing for learning to read in children's other language, English (Meschyan and Hernandez, 2006; Paulesu et al., 2000). Second, we hypothesized that bilingualism would yield language-specific changes in neural activation in brain regions classically associated with phonological processing and lexical access. Spanish has more predictable sound-to-print associations than French, and even more so than English, therefore, bilingual exposure to Spanish (more so than exposure to French) might result in greater recruitment of left posterior temporal brain regions associated with more direct phonological-based print-sound mappings. We further predicted that these bilinguals might show reduced recruitment of left frontal brain regions typically associated with more direct lexical access through more direct print-meaning mapping (Jamal et al., 2012; Paulesu et al., 2000; Tan et al., 2003).

An important design feature of the present study is that sound-to-print mapping is more direct in Spanish than in French. Therefore, we predicted that a comparison that includes Spanish-English and French-English bilinguals should reveal a continuum in which different types of orthographies impact bilingual children's emergent literacy. During functional Near Infrared Spectroscopy (fNIRS) neuroimaging children completed tasks involving an overt reading task with three conditions, including irregularly-spelled (e.g., *said*), regularly-spelled (e.g., *stop*), and pronounceable, but nonexistent pseudowords with high frequency spelling patterns (e.g., *dask*). These orthographic tasks have been previously used to help reveal different types of orthographic skills in typical development and dyslexia in children (Coltheart et al., 2001) as well as to reveal neural correlates of those skills in proficient adults (Fiebach et al., 2002; Heim et al., 2005). Like fMRI, fNIRS measures the brain's hemodynamic response, but uses infrared light sensors and emitters placed on the scalp. fNIRS has significantly increased our ability to image human language and higher cognition in development: tolerates movement, is quiet, and is "child-friendly," (see methods below for a more detailed description; see also Kovelman (2012), for a review). Using fNIRS neuroimaging in combination with our orthographic reading tasks, our study aimed to shed light on the impact of bilingual exposure on children's literacy during the key periods of brain organization for learning to read.

2. Material and Methods

2.1. Participants

Twenty-six (26) children participants included, 11 monolingual children (8 female and 3 male, mean age =8.09, SD =0.7), 7 Spanish-English bilingual children (1 female and 6 male, mean age =8, SD =1), and 6 French-English bilingual children (2 female and 4 male, mean age =8.25 years, SD =1) participated in the study. All children were between 7 and 9 years of age, and in Grade 2 or 3. Fisher's exact test for small sample sizes indicate that the distributions of males and females across groups was not significantly different (p=0.06). Please see Table 1 for participant background information. Inclusion criteria were applied to the bilingual participants to ensure that all bilingual children were receiving early-life exposure to their two languages as assessed with pre-experimental assessment screenings (e.g., regarding children's family and extended family languages, schooling, siblings and playmates, age of dual language exposure, etc.) and an extensive and previously published "Bilingual Language Background and Use Questionnaire" ("BLBUQ"; see Berens et al., 2013; Holowka et al., 2002; Jasińska and Petitto, 2013; Kovelman et al., 2008a, 2008b; Penhune et al., 2003; Petitto et al., 2000, 2001 for more details on this detailed bilingual language questionnaire). A similar inclusion criteria were applied to the monolingual children to ensure that their language rearing, schooling, and language experiences were monolingual English.

Table 1
Participant information.

	English Monolinguals	*Spanish-English Bilinguals*	*French-English Bilinguals*
Mean Age (SD)	8.1 (0.7)	8 (1)	8.3 (1)
Grade	2nd (n=6); 3rd (n=5)	2nd (n=2); 3rd (n=3)	2nd (n=2); 3rd (n=4)
Male: Female	3:8	6:1	4:2
AoE English	From birth	Age 0–3 (n=5); Age 5 (n=2)	Age 0–3
AoE Spanish	n/a	From birth	n/a
AoE French	n/a	n/a	Age 0–3 (n=3); Age 5 (n=3)

2.1.1. Language background

Participants were grouped as monolinguals or bilinguals based on the results of our inclusion assessments. As above, the factors included, for example, language use, input languages of their parents and extended family, the languages used in the home and at school, the age of first bilingual language exposure, and the relative amount of exposure in each language. Spanish-English bilinguals were exposed to Spanish at birth and to English between the ages of 0–5, an age range previously established as being vital for the neural establishment of typical dual language processing and dual language competency (Kovelman et al., 2008a; Jasińska and Petitto, 2013, 2014). These children were educated in English-only schools in the Unites States and were learning to read in Spanish at home with their native Spanish-speaking parents. French-English bilinguals were exposed to English or both English and French at home and to both French and English at school in the context of bilingual dual-language immersion programs in Canada. Monolingual children were exposed to English only, at home and at school in the United States. Please see Table 1 for background information.

2.1.2. Language proficiency

Spanish-English bilingual children and English monolingual children completed an expressive language assessment. Children were asked to generate narratives (in English, or in both English and Spanish) to a 1.5-min silent cartoon video. These narratives were transcribed by native Spanish and by native English-speakers using the CLAN program and CHILDES using standard guidelines for transcribing bilingual children's speech (Holowka et al., 2002; Petitto et al., 2001; Petitto and Kovelman, 2003). Transcripts were coded for the grammaticality (correct/incorrect phonological, semantic, and morpho-syntactic) content of each linguistic "utterance" (phrases, clauses, or sentences) produced by the participant, as well as how many story events were produced (MacWhinney, 2000). This analysis yielded grammatical accuracy scores for each participant and allowed us to assess whether participants had the same proficiency levels in English, and across both languages. A Welch independent-samples *t*-test was conducted to compare English language scores in English monolingual children and Spanish-English bilingual children. There was no significant difference in the scores for English monolingual children (M=90.21, SD=9.30) and Spanish-English bilingual children (M=76.62, SD=15.46); t(8.81)=2.10, p=0.07, although a near-significant trend of higher scores among English monolinguals was observed. A paired-samples *t*-test was conducted to compare Spanish-English bilingual children's language scores in English and Spanish. There was no significant difference in the scores for English (M=90.21, SD=9.30) and Spanish (M=76.62, SD=15.46); t(6)=−1.37, p=0.22.

French-English bilingual children completed the "Bilingual Language Background and Use Questionnaire" which provided indicators of children's language proficiency based on their language behavior. Of the six families of French-English bilingual children, two were "one parent, one language" families where either mom or dad was a native French speaker, and the other parent was a native English speaker, one family had two native French speaking parents, and of the remaining two families, parents spoke English and other siblings spoke both languages. Based on average language exposure each child had with his/her father, mother, siblings, and friends, children were exposed to English 55% of the time and to French 20% of the time between birth and 5 years of age, and to English 52% of the time and French 32% of the time between age 5 and age at testing (remaining percentage accounted for by additional languages spoken in the family).

All French-English bilingual children read regularly in French and preferred writing in French to English. Four families reported reading to their child in both English and French. Parents reported children first learned to read in English before the age of 5 (n=3), or at age 6 (n=3), and in French at the age of 6 or earlier. Most children perceived themselves as French-English bilinguals, as did members of their communities. Children accessed media (music, television, magazines, movies, and internet) in both English and French, albeit with greater English media consumption reflecting the majority English speaking context of Toronto, Canada. See Table 2 for French-English bilingual children's language background and use details.

In light of previous neuroimaging findings that showed structural brain changes and language competency differences based on a child's age of first bilingual language exposure, or AoE (Jasińska and Petitto, 2013, 2014; Klein et al., 2014; Kovelman et al., 2008a; Petitto et al., 2012), great emphasis was sought regarding our groups' early dual language experiences, resulting in the present final sample sizes studied. We thus offer first-time theoretically-motivated developmental neuroimaging data with two groups of bilingual child populations that are important for informing both theory and method for further developmental bilingual research.

Table 2
French-English bilingual children language background.

Item	*English*	*French*	*Both*
Preschool	5	1	0
Elementary School	0	4	2
Reading in Preschool (in school/for pleasure)	3	1	1
Reading in Elementary (in school/for pleasure)	0	1	5
Book Preference	2	2	1
Reading for Comprehension	3	3	0
Speaking Preference	4	1	1
Writing Preference	2	4	0
Parents Read to Child	2	0	4
Culture			
Others Perceive Child	2	0	4
Child Perceives Him/Herself	1	1	4
Language Maintenance			
Music	4	0	1
Television	2	0	3
Magazines	1	2	2
Movies	4	0	2
Internet	2	1	1
Conversing with Friends	1	0	5

2.2. fNIRS task & stimuli

Participants completed an overt word reading task during fNIRS neuroimaging. In English, the task included a total of 72 English words split across 3 conditions: 24 Irregular, 24 Regular, and 24 Pseudowords with high frequency spelling patters. Similarly, in French the bilinguals also read 24 regularly-spelled (e.g., *mal*), 24 irregularly-spelled (e.g., *oignon*), and 24 pronounceable but nonexistent pseudowords with high frequency (regular) spelling patterns (e.g., *reux*). Given that the extreme infrequency of irregular spellings in the Spanish, the Spanish stimuli only included 36 regularly-spelled (e.g., *viento*) and 36 pseudowords (e.g., *muey*). This was a block design with conditions split across randomized experimental blocks.

The Regular and Irregular word lists were modeled upon word lists typically included in grade 1–4 word lists, and the English and Spanish stimuli were also modeled after items in the bilingual version of Woodcock Johnson Language Proficiency Battery-Revised (Woodcock et al., 2001). The Pseudowords were created upon regularly spelled words by substituting one or two letters. In English, the words had an average length of 4.2 letters, 3.6 phonemes, 1.3 syllables, and 1054 frequency (MRC Psycholinguistic Database; Wilson, 1988). In French, the words had an average length of 4.3 letters, 3.1 phonemes, 1.2 syllables, and 365 frequency (Lexique; New et al., 2001). Finally, in Spanish, the words had an average length of 4.1 letters, 4 phonemes, 1.3 syllables, and 195 frequency (LEXMEX_V2.0; Silva-Pereyra et al., 2014). Paired *t*-tests between each condition pairing (regular-irregular, regular-pseudoword, irregular-pseudoword) in each language for every variable (word length, number of phonemes, number of syllables, and frequency) did not reveal any significant differences between word types ($p > 0.05$).

2.3. Procedure

We used a Dell computer running E-prime software to present the stimuli. The participants were seated approximately 30 cm from the stimulus presentation monitor. To minimize the bilingual switching effects, the children first completed the task in one language, and then in the other language, with order of languages counterbalanced for bilingual participants. This helped bilinguals enter 'monolingual-mode' for each task as not to induce language-switching effects.

Participants were instructed to read aloud each word as it was presented on the monitor. The block design began with 30 s of fixation, a set of instructions that reminded participants to read each word aloud, and 15-second rest periods between experimental blocks during which children saw a fixation in the middle of the screen. Within experimental blocks, the duration of word presentation was 2 s, followed by a 2 s inter-stimulus interval during which a fixation-cross appeared on the monitor. The children were asked to read aloud each word as they appeared on the screen as accurately as possible. The order of word-type blocks were counterbalanced. The entire experiment was approximately 7 min per language, for a total of 7 min for monolingual children and 15 min for both bilingual groups. Neuroimaging analyses only included the English data as these were more directly related to our study's goals and hypotheses, and because only the French but not the Spanish bilinguals were receiving formal schooling in their other language.

2.4. Imaging methods and data analyses

2.4.1. fNIRS data acquisition

Children's hemodynamic response was measured with a Hitachi ETG-4000 Near Infrared Spectroscopy system with 44 channels, acquiring data at 10 Hz (=sampling rate of 10 times per second). The

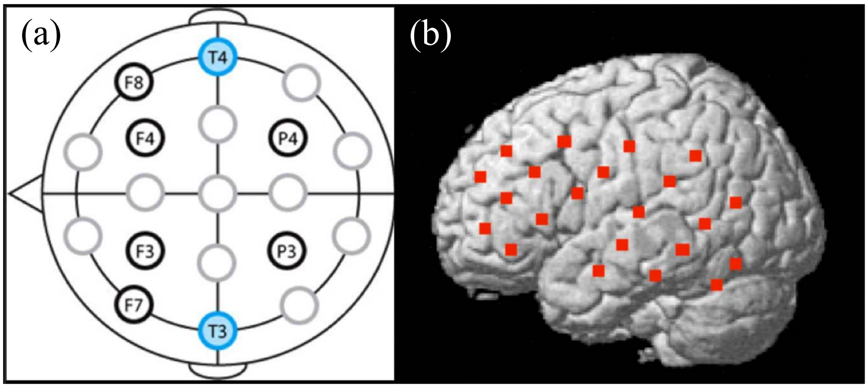

Fig. 1. Bilateral fNIRS placement (a) Key locations in Jasper (1958) 10–20 system. The detector in the lowest row of optodes was placed over T3/T4; (b) Probe array overlaid on a neuroanatomical template as estimated from fMRI scanning of the probe array (for details see Kovelman et al., 2009). .

lasers were factory set to 690 and 830 nm. The 18 lasers and 15 detectors were segregated into two 3×5 arrays (see Fig. 1). Once the participant was comfortably seated, one array was placed on each side of the participant's head. Positioning of the array was accomplished using the 10–20 system (Jasper, 1958) to maximally overlay the key regions of interest (for additional details, including neuroanatomical fMRI-fNIRS co-registration procedures to establish neuroanatomical precision of probe placements (Jasińska and Petitto, 2013, 2014; Kovelman et al., 2008c, 2009; Petitto et al., 2012; Shalinsky et al., 2009). Prior to recording, every channel was tested for optimal signal to noise ratio using Hitachi fNIRS inbuilt software. Digital photographs of left, right, front and top views were also taken of the positioning of the probe arrays on the participants' head prior to and after the recording session to ensure that probes remained in their identical and anatomically correct pre-testing placement.

2.4.2. fNIRS data preprocessing

The data were analyzed with Matlab-based NIRS-SPM (Jang et al., 2009; Ye et al., 2009). Using the modified Beer–Lambert equation, NIRS-SPM converts optical density values into concentration changes in oxygenated and deoxygenated hemoglobin response (HbO and HbR, respectively). Changes in HbO and HbR concentrations were filtered with a Gaussian filter and decomposed using a Wavelet-Minimum Description Length (MDL) detrending algorithm in order to remove global trends resulting from breathing, blood pressure variation, vasomotion, or participant movement artifacts and improve the signal-to-noise ratio (Jang et al., 2009). NIRS-SPM allows the spatial registration of NIRS channels to MNI space without structural MRI (Singh et al., 2005) by using a three dimensional digitizer (Polhemus Corp.) and provides activation maps based on the general linear model and Sun's tube formula correction (Sun, 1993; Sun and Loader, 1994). The spatial registration yielded values for Brodmann areas maximally represented by each channel.

2.4.3. fNIRS group analyses

We generated t-statistic deoxy-hemoglobin activation maps with left hemisphere views comparing Groups (Monolingual, Spanish-English Bilingual and French-English Bilingual) for each Word Type (English Regular, English Irregular, English Pseudowords). All statistical comparisons were thresholded at $p \leq .05$ and were uncorrected for multiple comparisons due to small group number.

2.4.4. fNIRS ROI analyses

Based on prior research that had identified orthography-specific modulation of left IFG and left STG regions as a function of English versus Italian reading experiences (Paulesu et al., 2000), we were especially interested in testing our experimental hypotheses for these neuroanatomical locations. NIRS-SPM spatial registration to MNI space yielded values for Brodmann areas maximally represented by each channel, which guided the selection of ROIs. As an added measure, we also performed a PCA across all children to identify clusters of channels with robust activity. From these PCA results, we matched these channels to the corresponding Brodmann areas to validate our ROI selection. 11 components emerged from the principal component analysis, of which the first three accounted for 50% of the total variance. Channels corresponding to bilateral STG were most correlated with the first component, bilateral IFG channels were most correlated with the second component, left posterior STG and supramarginal gyrus channels were most correlated with the third component. Thus, our ROIs included channels maximally overlaying left IFG (BA 45/47; Broca's area 44/45) and left STG (BA 42/22).

Following ROI identification, we conducted a between-group comparison to explore the impact of bilingual exposure on children's literacy in English. First, we generated t-statistic deoxy-hemoglobin activation maps with left hemisphere views comparing Word Type (Regular versus Irregular, Regular vs Pseudowords) for each Group. This was followed with a Group x Word Type analysis for each of the left hemisphere ROIs (IFG, STG), separately. Data were analyzed as a two level random intercept variance component multilevel linear model where the dependent variable represented change in HbO concentration using the statistical software package R (The R Core Team, 2013). For our multilevel model, values representing concentration changes in HbO were converted into z-scores (Matsuda and Hiraki, 2006; Otsuka et al., 2007; Schroeter et al., 2004; Shimada et al., 2004). We calculated the z-scores by computing the difference of the mean of the baseline (initial 15 s of each task) and each trial HbO value divided by the standard deviation of the baseline, for each channel. The first level of this model corresponded to individual NIRS channels, which were then nested in the second level of this model corresponding to participants. Our model incorporated crossed random effects (i.e., random intercepts) of participants and individual NIRS channels. First, a null model without predictor variables was computed. Next, the null model was expanded to include fixed effects and interaction terms at channels corresponding to our left hemisphere ROIs of left IFG and STG. The improvements in the fit of the full model over the null model were assessed using the log likelihood statistic. All ROI statistical comparisons were Bonferroni corrected.

We further examined if children's behavioral accuracy scores for each condition were related to activation in our left hemisphere ROIS of lefts IFG and STG. To do so, we performed a linear mixed effects model with our outcome variable as mean activation in the ROI, and accuracy score, word type, and group as predictor variables using the linear and nonlinear mixed effects (nlme) package (Pinheiro et al., 2016) in R. Posthoc analyses were conducted using the Post-Hoc Interaction (phia) package (R Core Team, 2013).

Table 3
Word reading accuracy rates (and standard deviations) by group and by language. .

	% Correct English Words			*% Correct French Words*			*% Correct Spanish Words*	
	Mean (SD)			Mean (SD)			Mean (SD)	
Language Group	*Reg*	*Irreg*	*Pseudo*	*Reg*	*Irreg*	*Pseudo*	*Reg*	*Pseudo*
English Monoling	92.9 (7.9)	83.3 (20.2)	84.6 (10.2)	n/a	n/a	n/a	n/a	n/a
Spanish Biling	86.9 (24.4)	59.5 (20.4)	73.8 (19.9)	n/a	n/a	n/a	68.1 (27.5)	66.0 (23.3)
French- Biling	93.1 (5.7)	66.7 (18.4)	80.6 (10.1)	82.6 (12.8)	68.1 (18.6)	73.6 (15.5)	n/a	n/a

3. Results

3.1. Behavioral results

All children showed more accurate reading of English regular words, followed by pseudowords, with the least accurate reading of irregular words ($F(2,36)=34.260$, $p < 0.001$, partial $\eta 2=0.614$; see Table 3). The same was true of Spanish and French. The Spanish-English bilingual children showed more accurate reading of Spanish regular words than pseudowords ($F(1,5)=16$, $p < 0.05$, partial $\eta 2=0.762$). The French-English bilingual children showed more accurate reading of French regular words, followed by pseudowords, with the least accurate reading of irregular words $F(2,8)=25.769$, $p < 0.001$, partial $\eta 2=0.837$).

There were no differences in English reading between French-English bilinguals and English monolinguals ($F(1,13)=1.741$, $p > 0.05$). Yet, Spanish-English bilingual children showed lower accuracy scores than English monolingual children in reading English irregular words (Word Type × Group; $F(2,28) =3.201$, $p < 0.05$, partial $\eta 2=0.242$). Finally, bilingual children read equally well in both their languages as there were no main effects of language in either of the bilingual groups (Spanish and English; $F(1,5) =0.3.523$, $p > 0.05$; French and English; $F(1,4) =0.518$, $p > 0.05$).

There was no significant main effect of gender on reading; $F(1,18) =0.442$, $p=0.514$. See Table 3 for detailed behavioral results.

3.2. Neuroimaging results

3.2.1. Main effects of group

When reading *Irregular words*, Spanish bilinguals showed greater parietal activation than monolinguals. French bilinguals showed greater left IFG activation than Spanish bilinguals. When reading *Regular words* both bilingual groups showed greater activation in left IFG region than English monolinguals. Furthermore, Spanish bilinguals also had greater left IFG activation than French bilinguals. When reading *Pseudowords* both bilingual groups showed greater activation in left posterior temporal regions relative to monolinguals. By contrast, the monolinguals showed greater left IFG activation than Spanish bilinguals and greater left anterior temporal activation than French bilinguals. French bilinguals also showed greater activation in middle/superior temporal and sensory-motor cortex during Pseudoword reading. See Fig. 2 and Table 4.

In sum, as compared to English monolinguals, during the Regular word task, the bilinguals showed greater activation in left IFG region, typically associated with greater analytical processing required during the search and retrieval of word meanings and complex analyses involved in speech-to-print mapping (Heim et al., 2005). By contrast, during the Pseudoword reading task, the bilinguals showed greater activation in left posterior temporal regions previously associated with phonological processes and more automated sound-to-print mappings (Fiebach et al., 2002).

3.2.2. Word type across language groups: ROI analyses

Left Inferior Frontal Gyrus: There was a main effect of word type with an improvement in model fit with word type over the null model ($\chi^2(6)=392.932$, $p < 0.001$), but no main effect of group. There were significant group by word type interactions with improvement in model fit with interaction terms over main effect model ($\chi^2(12)=87.999$, $p < 0.001$). Pairwise comparisons with Bonferroni corrections showed greater activation for Irregular versus Regular words for all groups (Irregular > Regular; Monolingual: Mean=0.146, SE=0.017, $p < 0.001$; French-English Bilingual: Mean=0.180, SE=0.028, $p < 0.001$; Spanish-English Bilingual: Mean=0.116, SE=0.020, $p < 0.001$). There was also greater activation for Regular versus Pseudowords for both Spanish and French bilinguals (Regular > Pseudoword: French-English Bilingual: Mean=0.173, SE=0.028, $p < 0.001$; Spanish-English Bilingual: Mean=0.188, SE=0.062, $p=0.020$). These effects can be visualized in Fig. 3.

There was no main effect of behavioral reading score on average activation in the left IFG and no significant group by word type by reading score interaction. No improvements in model fit with reading score predictor ($\chi^2(12)=0.012$, $p > 0.05$) or interaction terms ($\chi^2(20) =3.281$, $p > 0.05$) over main effect model were observed.

Left Superior Temporal Gyrus: There was a main effect of word type with an improvement in model fit with word type over the null model ($\chi^2(6)=1194.330$, $p < 0.001$), and no main effect of group. There were significant group by word type interactions with improvement in model fit with interaction terms over main effect model ($\chi^2(12)=698.7742$, $p < 0.001$). Pairwise comparisons with Bonferroni corrections revealed that all groups had greater activation for Regular versus Pseudowords (Pseudowords > Regular; Monolingual: Mean=0.405, SE=0.013, $p < 0.001$; French-English Bilingual: Mean=0.160, SE=0.024, $p < 0.001$; Spanish-English Bilinguals: Mean=0.280, SE=0.015, $p < 0.001$). Monolinguals and French bilinguals also showed greater activation for Regular versus Irregular words (Regular > Irregular; Monolinguals: Mean=0.193, SE=0.013, $p < 0.001$; French-English Bilingual: Mean=0.310, SE=0.024, $p < 0.001$). By contrast, Spanish bilinguals showed greater activation for Irregular versus Regular words (Irregular > Regular; Spanish-English Bilingual: Mean=- 0.183, SE=0.015, $p < 0.001$). See Fig. 3.

There was no main effect of behavioral reading score on average activation in the left STG, but a significant group by word type by reading score interaction with improvements in model fit with interaction terms over main effect model ($\chi^2(20)=22.686$, $p < 0.01$). Post-hoc pairwise comparisons between word type for each group were performed at three levels of the behavioral reading score: mean reading score (Mean=16.24), one standard deviation below the mean (Mean–1 SD =10.67), and one standard deviation above the mean (Mean +1 SD=21.83). For Spanish children whose reading scores were average and one standard deviation above the average, we observed a marginally significant differences between Regular and Pseudowords (Mean Reading Score; $\chi^2(1)=3.327$, $p=0.07$; Mean +1 SD Reading Score, $\chi^2(1)=3.604$, $p=0.06$). For monolingual children whose reading scores were one standard deviation above the average, we observed significant differences between Irregular and Regular words ($\chi^2(1) =10.647$, $p < 0.01$) and between Regular and Pseudowords ($\chi^2(1) =19.674$, $p < 0.001$).

In sum, word-type ROI analyses revealed both the impact of having bilingual experience and the type of bilingual experience. Left IFG activations revealed a bilingualism effect: only bilinguals had greater

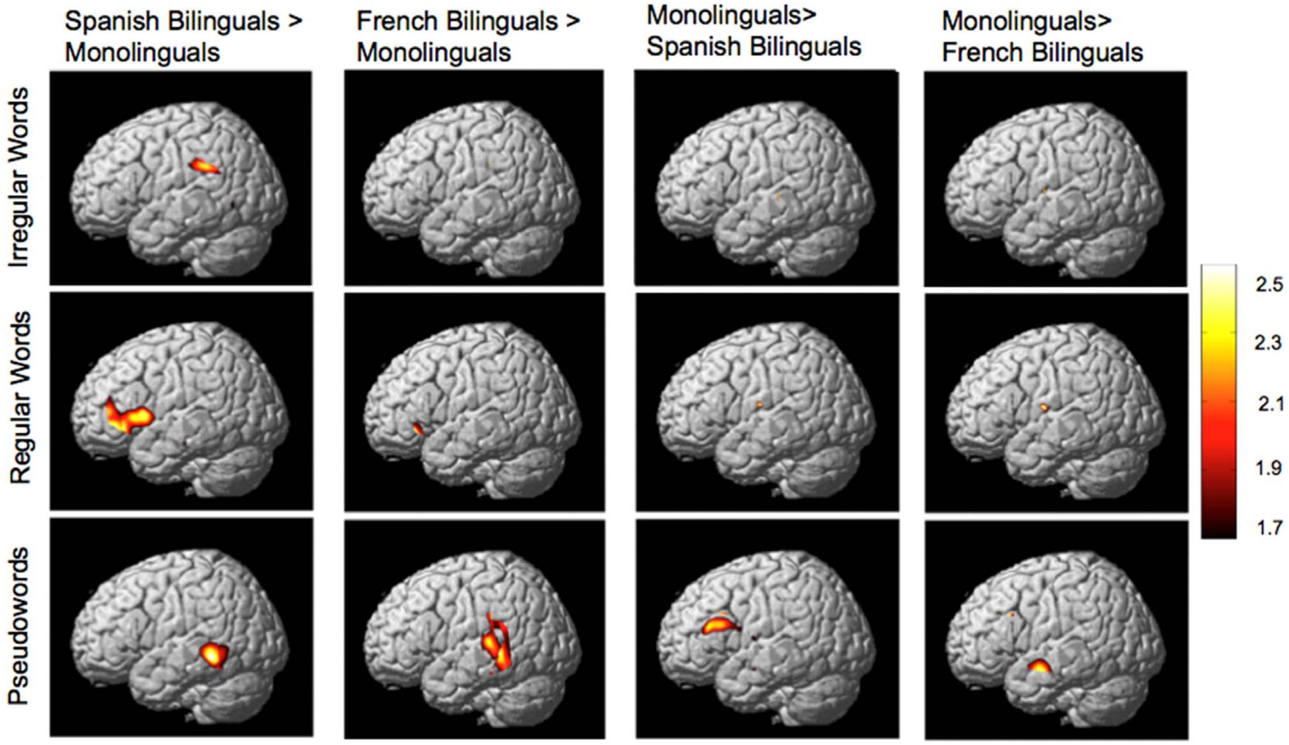

Fig. 2. Group differences in brain activation during the English reading tasks ($p < 0.05$, uncorrected).

left IFG activation for Regular as compared to Pseudoword reading tasks. Left STG activation showed the graded effect of orthographic experiences: both English monolinguals and French bilinguals showed greater left STG activation for regular than irregular words. By contrast, Spanish bilinguals showed greater left STG activation for irregular than regular words. Left STG activation was also predicted from children's reading accuracy: Monolingual children and (marginally) Spanish-English bilingual children showed differences in left STG activation between word types (see above), but only if their reading accuracy scores were average or above average. This finding may suggest that differences in activation are at least partially dependent on children's ability, that is, children who show at least average accuracy. Our model predicts that for children who show below average accuracy, neural differences between condition may not emerge. Importantly, we did not see differences related to accuracy score for Spanish-English bilinguals' activation during regular and irregular word conditions, suggesting that Spanish-English bilinguals' similar activation in left STG for regular and irregular words is not related to their lower irregular word reading accuracy relative to monolinguals and French-English bilinguals, but rather to the orthographic differences between Spanish and the other two languages English and French.

4. Discussion

Little has been known about the brain bases of bilingual literacy in children during the early periods when basic literacy skills are being established. Here, we investigated the impact of bilingualism on children's neural architecture for learning to read. We specifically tested the hypothesis that neural activation supporting reading varies as a function of the structural and orthographic characteristics of bilingual children's two languages. To achieve this important design

Table 4
Group comparisons in brain activations during English reading tasks ($p \leq .05$). .

Task/Group	Regions	BA	X	Y	Z	T
Irregular Words						
Sp Biling > Monoling	Left STG	22	−69	−36	24	0.66
Fr Biling > Sp Biling	Left IFG	45	−53	38	16	0.43
Regular Words						
Sp Biling > Monoling	Left IFG/triangularis	45/47	−55	32	4	1.05
Monoling > Fr Biling	Left STG	22/43	−67	−7	19	0.53
Fr Biling > Monoling	Left IFG/triangularis	45/47	−56	30	−2	0.57
Sp Biling > Fr Biling	Left IFG/triangularis	45	−58	23	5	1.13
Pseudowords						
Monoling > Sp Biling	Left IGF/triangularis	44/45	−57	23	21	1.07
Sp Biling > Monoling	Left ITG, MTG, FG	20/21/37	−69	−47	−3	1.09
Monoling > Fr Biling	Left MTG	21	−67	−4	−19	0.92
Fr Biling > Monoling	Left ITG, MTG, STG, FG	20/21/22/27	−69	−38	7	1.09
Fr Biling > Sp Biling	Left MTG, STG	21/22	−69	−18	1	0.10
	Sensory Motor	6/43	−65	1	23	0.10

*Note: Fr-Biling = French-English bilinguals; Sp Biling = Spanish-English bilinguals, Monoling = English monolinguals; MNI coordinates, BA = Brodmann Area.

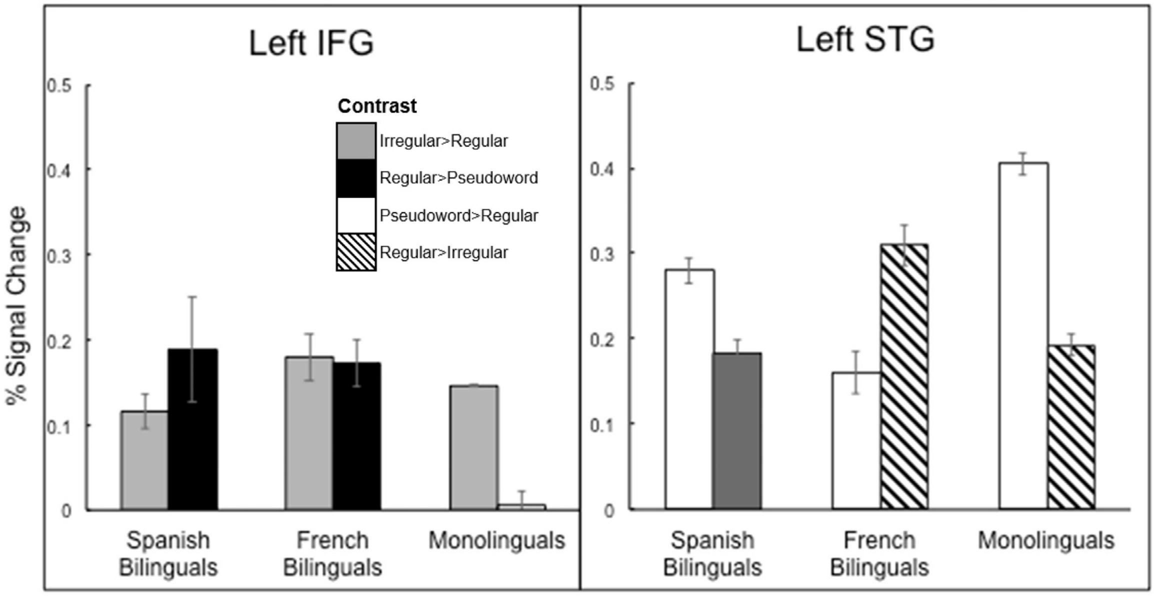

Fig. 3. Region of interest analyses for left IFG and STG regions for each group and word type.

feature of the present study, we selected languages that differed in the degree of predictability of their sound-to-print correspondences. Here, bilingual children acquiring English, in addition to either Spanish (Spanish-English bilingual children), or French (French-English bilingual children) were studied, as compared with monolingual English children. Whereupon Spanish has consistent sound-to-print correspondences ("phonologically transparent" or "shallow"), French correspondences are more opaque, with English being even more opaque (as English has both phonologically transparent, and, crucially, "phonologically opaque" or "deep" correspondences). We predicted that differences in sound-to-print correspondences among the languages would render a continuum in which different types of language structure/ orthographic pairings would impact bilingual children's neural engagement and processing of word-reading tasks in English. Consistent with our hypotheses and predictions, we found that bilingual exposure to French or Spanish had a language-specific impact on children's engagement of the left inferior frontal and posterior temporal regions during English word reading tasks.

Previously, a cornerstone cross-linguistic comparison revealed greater left IFG activation in English speakers and greater left STG activation in Italian speakers during pseudoword reading task (Paulesu et al., 2000). Italian has a transparent orthography, as such, in a pseudoword reading task, each letter has a direct one-to-one correspondence to a phoneme, and depend to a greater extent on direct phonological mapping that is largely supported by the left STG. Remarkably, our present developmental results with French-English and Spanish–English bilingual children also revealed greater left IFG activation in monolinguals but greater left STG activation in bilinguals during a Pseudoword reading task in English. These convergent findings for Spanish and French bilinguals are especially notable given that the two bilingual groups came from different environments, in USA and in Canada, and differ in the schools they attended. Taken together the findings suggest that bilingualism can have a significant impact in children and their brain's functional organization for learning to read. Below we further discuss our findings in terms of their contribution to theories of bilingual reading acquisition and neurodevelopmental activation patterns—or the "neural signature" of bilingual language development. Although the construct of a "neural signature" for bilingualism had been first offered for adult bilinguals (e.g., Kovelman et al., 2008b), the present study joins only a handful of neuroimaging studies to explore whether the phenomenon of a neural signature may exist in the young developing bilingual child and emergent reading (e.g., Jasińska and Petitto, 2013, 2014).

We begin by discussing the region of interest analyses for the three word types (Irregular, Regular, and Pseudowords). We also ask whether our results for bilinguals are consistent with well-documented findings for monolingual adults (Fiebach et al., 2002; Heim et al., 2005). Similar to previously studied monolingual adult readers, our child participants showed greater left frontal activation for Irregular than Regular words and greater left temporal activation for Regular than Pseudowords (Fiebach et al., 2002). For adults, these findings have been interpreted to suggest that left frontal regions play a greater role in processing direct sound-to-print assembly through phonology-semantic pathway, which is especially difficult for irregularly spelled words. By contrast, left temporal regions are thought to play a greater role in supporting words' meaning and lexicality status, which are present for Regular words but absent in Pseudowords. Our findings, therefore, are generally consistent with the adult literature, and we now turn our attention to the impact of bilingualism on learning to read.

Theories of bilingual word processing suggest that even when using their other language, both languages remain active, thereby creating fruitful ground for cross-linguistic interaction (Kroll et al., 2008). Developmental research with young bimodal sign-speech bilinguals revealed that these interactive mechanisms are at play from earliest milestones in language acquisition (Holowka et al., 2002; Petitto and Kovelman, 2003; Petitto et al., 2001). This cross-linguistic interaction is thought to carry implications for bilingual reading acquisition (see introduction; Proctor et al., 2010). Indeed, while the children in the present study had comparable Regular and Pseudoword reading accuracy in English, the bilinguals had lower Irregular word accuracy in English. This difference reached significance for Spanish bilinguals. As both Regular and Irregular words were drawn from early grades' common word reading lists and were equated on multiple linguistic characteristic (e.g., length, syllables), we suggest that bilingual children's experience with more phonologically-transparent orthographies may impact their acquisition of irregular words. The neuroimaging evidence discussed below further supports this interpretation.

4.1. Irregular words

An important feature of our bilingual experimental design was that while both Spanish and French have better sound-to-print predictability than English, this predictability is better in Spanish than in French. The behavioral findings revealed that only Spanish bilinguals, but not French bilinguals, were significantly worse at reading irregular words than English monolinguals. fNIRS findings for irregular word reading in Spanish-English bilinguals revealed that as compared to monolinguals, the bilinguals had greater left posterior temporal activation during this task. Similarly, the ROI analyses revealed that English monolinguals and French bilinguals showed greater left STG activation for regular than irregular words. By contrast, the reverse was true for Spanish bilinguals who showed greater left STG activation for irregular than regular words. Taken together, convergent behavioral and neuroimaging findings for the irregular task suggest that bilingual exposure to phonologically-transparent language like Spanish may result in increased reliance on direct sound-to-print mapping mechanisms as supported by left STG. This takes place even when the word's orthographic characteristics more heavily weigh toward the use of more complex, left IFG-supported reading pathways.

It might be expected that Spanish-English bilinguals would show similar activation patterns for both irregular and regular words in the left STG, reflecting their use of *similar* sound-to-print mapping mechanism for reading both regularly and irregularly spelled words. However, this was not observed and we believe that the Spanish language's heavy reliance on direct sound-to-print mapping predicts that this would be the case, and why. The Spanish bilingual who reads irregularly spelled words with greater reliance on sound-to-print mappings would result in inaccurate reading and require their re-analysis. That this does not occur, in turn, may suggest further evidence that the Spanish-English bilingual tacitly differentiates the two language typologies during reading, and may suggest the use of *different* neural routes. Indeed, it may suggest a fascinating alternate route used when encountering irregular words in the left STG as indicated by increased activation observed in Spanish-English bilinguals but not the English monolinguals or French-English bilinguals (where the language typologies rely less so on strong "shallow" sound-to-print mappings)—an intriguing hypothesis that will require further investigation.

Fortunately, however, effective literacy instruction can make an important impact on bilinguals learning to read (Goldenberg, 2011). As our findings reveal with a large sample of Spanish-English bilinguals collected across several states, schools, and educational programs spanning the United States, Spanish-English bilinguals have lower performance during irregular and passage comprehension tasks that were predictable and expected from the shallow typology of the Spanish language (Kovelman et al., 2008a; Berens et al., 2013). By contrast, bilinguals attending simultaneous dual-language immersion programs (50/50 bilingual exposure from kindergarten) *outperformed* bilinguals attending sequential transitional programs (Spanish first, English second; Berens et al., 2013). Furthermore, among the simultaneous dual-immersion programs, children with early bilingual exposure (before age 4) to English, and who were educated in whole-language approach programs, *outperformed* early bilinguals in code- or phonics-based programs. (It is important to note that code-based programs were indeed best for *late*-exposed bilinguals; Kovelman et al., 2015.) Taken together, the findings suggest that knowing bilingual children's language typology and age of first bilingual language exposure might help guide educators towards optimal approaches for literacy instruction for young bilinguals.

4.2. *Regular words*

Between-group comparisons for other word types revealed that during the Regular word reading task the bilinguals showed greater left frontal activation relative to the monolingual English group. This effect was stronger for Spanish than French bilinguals. Similarly, ROI analyses for the left IFG region revealed a significant group by word type interaction, suggesting that only the bilingual groups showed greater left IFG activation during Regular than Pseudoword tasks. As can be seen in Fig. 2 (and Table 4), these greater activations stem from BA 47/45 regions typically associated with lexico-semantic word processing (Heim et al., 2005). As discussed earlier, even when using only one of their languages, bilinguals have access to both linguistic systems (Kroll et al., 2008). Therefore, given that the bilinguals were learning to read in two languages with a shared alphabetic system, it is possible that greater left IFG engagement during the Regular word reading tasks reflects the greater extent of lexico-semantic search through the dual lexicon.

4.3. *Pseudowords*

One of the cornerstone studies to reveal cross-linguistic impact on brain's organization for orthographic processing was the study by Paulesu et al. (2000). This study used multiple reading conditions, but it was the Pseudoword reading task that was best at revealing group differences. Italian speakers had greater activation in left STG while English speakers had greater activation in left IFG. Group differences were most apparent during the Pseudoword reading condition likely because this condition places greater reliance on phonological reading skills than the reading of familiar word items thereby better obviating cross-linguistic differences in reading in phonologically-transparent and phonologically-opaque languages (Paulesu et al., 2000). Remarkably, our developmental findings for both French and Spanish bilinguals revealed the same effect. During the Pseudoword reading task in English, the language that was common to all our participants, the bilinguals showed greater left STG and lower left IFG activation, relative to monolinguals.

The findings therefore demonstrate that cross-linguistic reading experiences affect bilingual children's neural architecture for learning to read early in development. Note that the findings for this and other reading tasks also revealed differences between the bilingual groups, including greater left STG activation in French bilinguals for Pseudoword task and greater left IFG activation for Regular word task in Spanish bilinguals (Table 4). These differences may have stemmed from cross-linguistic as well as socio-cultural and educational differences between the two groups who were tested across two different countries. Nevertheless, it is the convergence between the two bilingual groups, as found for the Pseudoword task, that is key in demonstrating that bilingual exposure to a more phonologically-transparent orthography can impact children's brain organization for learning to read in English.

4.4. *Theoretical and developmental implications*

Literacy theories have suggested that learning to read is fostered by a strengthening of the self-organizing network involving phonological, semantic, and orthographic associations (Perfetti et al., 2006, 2007), in which left IFG and STG regions play differential roles for supporting words with various levels of phonological transparency (Pugh et al., 2001). Researchers agree that there are multiple successful paths to learning to read in terms of how children strengthen this network and its neural correlates, such that even those with dyslexia can develop successful compensatory mechanisms (Shaywitz et al., 2003). Contrasting with biogenetic impact on learning to read, bilingualism expands our understanding of how learning contexts impact the variability and plasticity of the neural bases for learning to read. Prior research has shown that Italian-English bilinguals with dyslexia and/or poor literacy skills outperformed English monolinguals with dyslexia on multiple phonological reading measures (D'Angiulli et al., 2001). The present new data now show that bilingual learners of phonologically transparent orthographies show greater activation in left STG region, thereby constituting an index of a neural signature in the young bilingual child involving differences between transparent versus non transparent orthographic systems. It further sheds light on a dysfunction that is often thought to be at the very route of developmental dyslexia (Raschle et al., 2012). Taken together, the findings raise the fascinating possibility that studies of bilingual language learning and reading may provide a unique window into the extent and variability of the functionality and developmental plasticity of the left STG region. New insights may also arise regarding the extent to which the left STG region may undergo neurodevelopmental change in atypical children populations learning to read.

4.5. Limitations and future directions

The findings drawn from our study need to be interpreted bearing in mind our small sample size. As such, future directions of this research need to include corroborating findings with larger samples and across additional language pairings. We predict that the pattern of results for bilingual children who are speakers of an opaque and a transparent language such as English and Spanish compared with bilingual children who are speakers of two opaque languages will hold across additional languages and bilingual samples. We do also note that some potential patterns could emerge with a larger sample size. For example, Spanish-English bilinguals' behavioral results showed higher standard deviation than English Monolingual and French-English bilinguals on some tests. Subsequent investigation will allow us to examine any additional between and within group variances more thoroughly.

Our participants were tested both in USA and in Canada, which allowed us to recruit two populations of bilingual speakers, Spanish-English and French-English. This would not have been possible had our study only been limited to one country. The current study represents a design advantage, allowing comparison between bilinguals who vary in the orthographic depth of their second language, Spanish or French. However, although there are strong similarities between the linguistic context of USA and Canada, participants coming from different regions in two countries add to a heterogeneous sample. As such, we must consider the possibility that differences between Spanish-English and French-English bilinguals may also be partially driven by differences in Canadian versus American environment in which our participants are growing up. Future research directions include larger samples drawn from comparable communities and additional language pairings that vary along the continuum of transparent to opaque orthographies during ages critical for the emergence of literacy.

5. Conclusions

Theories of learning to read have hypothesized that children begin by learning to compute both complex and more direct language-to-speech transitions by engaging left frontal and temporal regions of the brain (Pugh et al., 2001). The functionality of these left hemisphere regions may change differently as a factor of reading experience with different orthographies (Das et al., 2011). While it has been well-established that sequential exposure to two orthographies results in the use of the child's first-exposed language skills and their neural correlates towards learning to read in the second language (Tan et al., 2003), it remained unclear if *early life bilingual language* exposure can also have a significant impact on children's brain organization for learning to read. The present findings suggest that, yes, indeed, there a significant impact of early life bilingualism on children's developing brain. Both French-English and Spanish-English bilinguals demonstrated differential recruitment of left frontal and temporal regions when reading in English, as compared to English monolinguals. The differences in both reading performance and brain activation were greater for Spanish-English than French-English bilinguals, especially when reading Irregular words, suggesting an orthography-specific plasticity. The findings help illuminate the brain bases of learning to read in all children as well as the extent, plasticity, and neurodevelopmental bases of reading in the young bilingual child. The findings further carry important implications regarding educational practices that may be used to facilitate reading acquisition in young bilingual children from different linguistic backgrounds.

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