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Does Growth in the Executive System of Working Memory Underlie Growth in Literacy for Bilingual Children With and Without Reading Disabilities?

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Abstract

This cohort-sequential study explored the components of working memory (WM) that underlie second language (L2) reading growth in 450 children at risk and not at risk for reading disabilities (RD) whose first language is Spanish. English language learners designated as balanced and nonbalanced bilinguals with and without risk for RD in Grades 1, 2, and 3 at Wave 1 were administered a battery of cognitive (short-term memory, WM, naming speed, and inhibition), vocabulary, and reading measures in Spanish and English. These same measures were administered 1 and 2 years later. Two important findings occurred: First, growth in the WM executive component was significantly related to growth in English word identification and passage comprehension when competing measures (phonological processing, naming speed, inhibition, and fluid intelligence) were entered into the multilevel growth model. Second, children defined as at risk for RD in Wave 1 had lower intercepts than children not at risk at Wave 3 across several measures of cognition, language, and achievement. However, except on measures of the executive component of WM, no significant group differences in linear growth emerged. These findings suggest that growth in L2 reading was tied to growth in the executive system of WM.

Keywords

working memory, ELL, cognitive processing, reading, language acquisition

School achievement is lower for children who are Latino than many other ethnic groups (August & Hakuta, 1997; Lesaux, Crosson, Kieffer, & Pierce, 2010). Further, these children are more likely to have reading difficulties (e.g., English word identification and comprehension) than other minority and Caucasian children (August & Hakuta, 1997; Lesaux et al., 2010; McCardle, Keller-Allen, & Shuy, 2008). Of those children with reading difficulties, several may be at an increased risk for reading disabilities (RD). Unfortunately, the reason behind the prevalence of reading difficulties in children who are English language learners (ELLs) in the public school system is unclear because neither a method for accurate identification nor a consistent definition across states exists (e.g., McCardle et al., 2008). These issues underscore the need for better tools and methods for accurately identifying ELL children at risk for RD.

Our purpose in this study was to explore those cognitive processes that may account for reading growth in ELL children at risk or not at risk for RD. One process that may account for some of the difficulties experienced by children at risk for RD is working memory (WM). Recent studies have found a significant correlation between WM and reading performance in ELL children at risk for RD (e.g., Swanson, Orosco, & Lussier, 2012; Swanson, Sáez, Gerber, & Leafsted, 2004). This significant relationship has been found between WM and reading within and across language systems (e.g., Swanson et al., 2004). However, the component of WM most likely to uniquely predict second language (L2) reading growth is unclear. One framework to capture the contribution of multiple components of WM to L2 reading is Baddeley's multicomponent model (Baddeley & Logie, 1999).

According to Baddeley's multicomponent model (Baddeley, 2012; Baddeley & Logie, 1999), WM is comprised of a central executive system that interacts with a set of two subsidiary storage systems: the speech-based phonological loop and the visual-spatial sketchpad. The phonological loop is responsible for the temporary storage of verbal information; items are held within a phonological

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store of limited duration, and the items are maintained within the store through the process of subvocal articulation. The phonological loop is commonly associated with short-term memory (STM) because it involves two major components discussed in the STM literature: a speech-based phonological input store and a rehearsal process (see Baddeley, 1996, for a review). The visual-spatial sketchpad is responsible for the storage of visual-spatial information over brief periods of time and plays a key role in the generation and manipulation of mental images. The central executive is involved in the control and regulation of the WM system. According to Baddeley (Baddeley, 2012; Baddeley & Logie, 1999), the central executive coordinates the two subordinate systems, focuses and switches attention, and activates representations within long-term memory (LTM). This model has been revised to include an episodic buffer (Baddeley, 2000), but support for the tripartite model has been found across various age groups of children (e.g., Gathercole, Pickering, Ambridge, & Wearing, 2004).

To address the role of WM as possibly underlying growth in L2 reading for children at risk for RD, two models are considered. The first model views ELL children's phonological system as more developed than their executive system, and therefore, the development of STM storage will consequently supersede any contribution that the executive component of WM would make to L2 reading. Indirect evidence for this assumption comes from studies linking the phonological system to a number of L2 processes (e.g., language and reading) during the early childhood years (Baddeley, Gathercole, & Papagno, 1998). There is also some literature suggesting that the contribution of the executive component of WM to various criterion measures is unstable across age groups and that STM eliminates the predictive contribution of executive WM to various measures (Colom, Rebollo, Abad, & Shih, 2006; Shahabi, Abad, & Colom, 2014).

A simple version of the above hypothesis states that efficiency in accessing and storing phonological information plays a major role L2 reading and language acquisition. One mechanism that underlies accessing and storing phonological information is a child's knowledge about the sound structures in language. Several studies show that measures of verbal STM and phonological processing are strongly associated (see Alloway, Gathercole, Willis, & Adams, 2004, pp. 87–88, for a review), and therefore, greater phonological processing abilities are related to higher STM scores because they tap a common processing substrate. Another mechanism that may mediate the influence of STM storage on L2 reading and language acquisition is naming speed. Rapid naming is assumed to enhance the effectiveness of subvocal rehearsal processes and hence reduce the decay of memory items in the phonological store prior to output (e.g., Henry & Millar, 1993). Naming speed has been interpreted as a measure of how quickly items can be encoded and rehearsed within the phonological loop (e.g., Bonifacci, Giombini, Bellocchi, & Contento, 2011; McDougall, Hulme, Ellis, & Monk, 1994).

In contrast to a phonological storage model, the second model views growth in the executive component of WM (i.e., controlled attention) as underlying children's L2 growth in reading performance. This model assumes there is unique variance related to the executive system of WM that contributes to children's L2 performance. The executive component of WM is traditionally defined as controlled attention (e.g., Baddeley, 2012; Engle, 2002; Engle, Tuholski, Laughlin, & Conway, 1999). For this study, controlled attention is operationally defined as the residual variance left in WM when STM has been partialed from the analysis (e.g., see Bayliss, Jarrold, Gunn, & Baddeley, 2003; Engle et al., 1999, for a discussion). We assumed that this residual variance (i.e., controlled processing) is partially reflected in activities that involve the updating of information as well as the inhibition of competing information from the targeted information. Thus, in contrast to the aforementioned hypothesis that suggests phonological storage processes play a more dominant role in the growth effects of WM on ELL children's L2 reading performance, this model assumes that executive processes also play a unique and significant role.

A possible mechanism that may mediate controlled attention is the inhibition of competing language systems (Bialystok, 2011; Bialystok & Feng, 2009; Bonifacci et al., 2011). A number of studies that have shown proficiency in L1 and L2 positively influence executive functioning, flexibility, and intentional control (e.g., Bialystok, 2011). These studies suggest that navigating between two languages, having frequent opportunities to inhibit one language when using the other, and holding linguistic information in mind while manipulating another are related to the development of executive processes. Because inhibition processes have been attributed to WM (Engle, 2002; Friedman et al., 2007), it seems probable that individual differences related to language inhibition may play an important role in WM performance.

In general, the two aforementioned models provide competing interpretations on the primary role of WM in reading growth. The first model suggests that growth related to phonological access and storage (i.e., the phonological loop) underlies reading difficulties in children at risk for RD, whereas the second suggests that growth in the executive system of WM underlies some of the difficulties in reading acquisition. To compare the contribution of each model to L2 reading growth, an accelerated or cohort-sequential design was used. Of particular interest in this study is the question as to whether reading growth of ELL children who vary in language and reading proficiency is related to the independent contributions of growth in WM components. To explore the contribution of WM to growth in L2 reading, this study addressed two questions.

Question 1

Is There a Significant Relationship Between Components of WM and Reading Growth, and Is Such a Relationship Dependent on the Type of Reading Task?

On the assumption that WM contributes important variance to L2 reading outcomes, the question emerges as to which components of WM predict L2 reading outcomes. On the assumption that difficulties on measures of the phonological loop are related to a weak phonological store and/or phonological traces that are not constantly refreshed by rehearsal, performance on measures that tap the phonological loop may account for difficulties related to word identification. On the other hand, difficulties in L2 reading comprehension may involve a more direct manipulation of information, a characteristic of the executive component of WM (Baddeley, 2012). Several studies have found that although ELL children may progress over time in word recognition skills, their reading comprehension lags from that of their peers (e.g., Lesaux et al., 2010; Mancilla-Martinez & Lesaux, 2010), suggesting that different processes from word recognition are involved. Because the executive component of WM involves the active manipulation of information while also mentally storing other information (Baddeley & Logie, 1999; Gathercole et al., 2004), a significant relationship may be expected to occur with L2 reading comprehension performance.

Several processes besides WM have been attributed to reading difficulties, and therefore, it is important to consider whether measures of WM are uniquely related to L2 reading outcomes. Previous studies have attributed proficiency in L2 literacy to phonological processing (Durgunoğlu, Nagy, & Hancin-Bhatt, 1993; Leafstedt & Gerber, 2005), oral language (Farnia & Geva, 2011; Gottardo, Collins, Baciu, & Gebotys, 2008), naming speed (Lindsey, Manis, & Bailey, 2003; Manis, Lindsey, & Bailey, 2004), and inhibition (Swanson et al., 2004), to name a few processes. Therefore, the present study determines whether the study of WM contributes significant variance in the predictions of L2 reading beyond the aforementioned processes.

In sum, we predict that the phonological loop (STM) plays a significant role related to growth in English word recognition, whereas the executive component of WM will be significantly related to reading comprehension. The competing hypothesis, however, is that the executive component of WM plays a secondary role to the phonological loop and related cognitive processes. Therefore, entry of the phonological loop, as well as the other aforementioned covariates (e.g., L1 and L2 vocabulary, phonological processing, naming speed, and inhibition), would eliminate any significant contribution of the executive system of WM to L2 reading.

Question 2

Are There Growth Differences in the Executive Component of WM as a Function of Children at Risk and Not at Risk for RD Who Also Vary in Bilingual Proficiency, and If So, Do These Differences Merely Reflect an Artifact of STM Storage and/or Related Cognitive Processes?

This question is addressed by dividing the sample into balanced and nonbalanced language subgroups. That is, all children in this study were bilingual to some extent but varied in proficiency in the two languages. Balanced bilingual children we assumed have high levels of competencies in both languages (in this case, English and Spanish), whereas nonbalanced bilinguals were assumed to reflect greater proficiency in their first language (in this case, Spanish; Cummins, 1979). Thus, the contribution of growth in the executive component to reading proficiency was addressed in three ways.

First, balanced and nonbalanced language subgroups that vary in reading proficiency are compared across several cognitive measures presented in English and Spanish. Although previous studies have found that several of the cognitive measures administered are language independent (e.g., Swanson et al., 2004, 2012), it is possible that growth on these measures may be more apparent in one language system than another. Thus, of interest was whether there was a qualitative change in WM in performance when compared to other cognitive processes over three testing waves spaced 1 year apart. This qualitative change, as suggested by an interaction with testing wave, may be related to language status, reading status, or both factors. If no significant interaction occurs related to testing wave on any of the cognitive measures, then it can be assumed that the classification of RD that occurred at Wave 1 was maintained across all three testing waves.

Second, growth estimates were computed across the various cognitive measures. Previous work has already established that ability group differences occur across a broad range of cognitive measures at Wave 1 (Swanson et al., 2012), but whether ability group differences can be tied to actual growth in WM or growth in other related cognitive process has not been established in the literature. Because ELL children have been shown to improve substantially on measures of word recognition when compared to comprehension (e.g., Lesaux et al., 2010; Mancilla-Martinez & Lesaux, 2010), it is possible that children at risk for RD catch up on measures of phonological processing (i.e., higher slopes), whereas their growth on WM measures remains smaller (lower slopes) than children not at risk.

Finally, assuming that ability group differences emerged on the executive measures of WM, a regression model compared the subgroups after entering measures of phonological processing (STM) into the model. We reasoned that if the executive component of WM is a fundamental processing deficit that underlies the RD classification, then the significance of this classification variable would be sustained when phonological processing measures are entered into a regression analysis. To test this assumption, one of our regression analyses included the classification of RD as a contrast variable, whereas the other analysis treated RD as a continuous variable. Previous studies that have examined RD difficulties in ELL children have used a cut-off score (e.g., 25th percentile) in reading skills with English monolingual children (e.g., Boscardin, Muthén, Francis, & Baker, 2008; Catts, Compton, Tomblin, & Bridges, 2012; Gottardo et al., 2008; Lipka, Lesaux, & Siegel, 2006; Stanovich & Siegel, 1994) and ELL children (e.g., Geva, Wade-Woolley, & Shaney, 1997; Swanson, Orosco, Lussier, Gerber, & Guzman-Orth, 2011) for a determination of potential risk for RD. The categorization of data (e.g., reading and language measures) is not recommended when compared to analyzing a continuous measure (see MacCallum, Zhang, Preacher, & Rucker, 2002, for an extensive discussion on the limitation of dichotomizing). Thus, the question emerges as to whether a comparison between the two approaches would yield different outcomes (e.g., differences in power and/or increases in Type 1 error) in support of the notion that L2 reading proficiency is predictive of executive processing.

Method

Participants

Four hundred and fifty students in Grades 1 (n = 139), 2 (n = 138), and 3(n = 173) from three large school districts in the southwest United States participated in this longitudinal study. The first wave of data collection was completed in the spring of 2010. The sample consisted of 205 boys and 245 girls. All children were Hispanic. School interviews indicated that children's primary home spoken language was Spanish (80%). Fourteen percent of the sample spoke both English and Spanish at home, whereas the remainder of children primarily spoke English (6%). Ninety-six percent of the sample participated in a federal free and reduced lunch program. Classroom reading instruction was in English, and the reading programs in each school district placed a heavy emphasis on phonics instruction.

The second wave of the testing, 1 year later, included 396 Hispanic children in Grades 2 (n = 115), 3 (n = 123), and 4 (n = 158). The attrition of children who dropped out of the study was due to children moving to another school district or back to Mexico. The retained sample consisted of 187 boys and 209 girls. Home interviews indicated that children's primary home spoken language was Spanish (81%), English and Spanish (10%), or English (9%). Ninety-seven percent of the sample participated in the free and reduced lunch program.

The third wave of the testing, 2 years later, included 337 Hispanic children in Grades 3 (n = 101), 4 (n = 97), and 5 (n = 139). Again, the attrition of children who dropped out of the study was due to moving out of the school district or moving back to Mexico. The retained sample consisted of 156 boys and 181 girls. Interviews for this sample indicated children's primary home spoken language was Spanish (83%), English and Spanish (10%), or English (7%). Ninety-six percent of the sample participated in the free and reduced lunch program.

Because of attrition, comparisons were made between children retained and those not retained on measures of achievement, chronological age, and gender representation. No significant difference occurred between children retained (n = 337) and not retained (n = 113) as a function of gender, $\chi^2(1, N = 450) = .29$, $p = .58$, or grade level, $\chi^2(2, N = 450) = 4.65$, $p = .10$. A MANOVA was computed on the English reading (word identification and passage comprehension) and English and Spanish receptive vocabulary standard normed referenced scores at Wave 1. No significant differences in vocabulary and reading scores occurred between the four groups as a function of retention, Wilks' $\lambda = .98$, $F(4, 391) = 1.56$, $p = .18$.

Risk status. In terms of common cut-off score designations for RD, the 25th percentile on normed reading measures is commonly used to designate risk for RD, and therefore, it is useful to use cut-off scores as practiced in the schools (Fuchs et al., 2008; Stanovich & Siegel, 1994). Reading measures in English were selected for defining the sample as at risk for RD because this was the primary language of instruction in the reading classrooms across all three testing waves. Although our study attempts to identify potential cognitive variables that underlie risk for RD in ELL children, several studies suggest a categorical approach to study RD in many cases is an artifact of the cut-off point (Branum-Martin, Fletcher, & Stuebing, 2013). However, for comparative purposes, we divided the sample along the cut-off score commonly referred to in the literature and compared those outcomes when leaving the classification measures as continuous measures.

Because the focus of this study is on English reading proficiency, children who performed in the lower 25th percentile in English word recognition and reading comprehension at Wave 1 were considered at risk for RD. Thus, our criteria for identifying participants at risk for RD were as follows: children who scored in the average range (85–120) on measures of fluid intelligence (*Raven Progressive Matrices*; Raven, 1976) and math (e.g., arithmetic subtest of the *Wide Range Achievement Test* [WRAT]; Wilkinson, 1993) but scored below the 25th percentile (or <90 standard score) on the *Woodcock-Muñoz Language Survey* (WMLS; Woodcock, Muñoz-Sandoval, & Alverado, 2005) subtests on English measures of word recognition and passage comprehension. It is important to note that other children (n =

63) were tested but were excluded from the data analysis because of low scores on measures of fluid intelligence and math performance. This was done because our focus was on reading and not general achievement difficulties.

As with the definition of RD, the definition of ELL or bilingual proficiency is also controversial (i.e., whether to use expressive vs. receptive language, frequency of English spoken at home, etc.). The first language for all children participating in this study was Spanish. Their performance on the *California English Language Development Test* (CELDT) was at the low proficiency level. For this study, however, English language learners (i.e., nonbalanced bilinguals) were operationally defined as achieving English receptive language (vocabulary) scores below a normed standard score of 80 on the *Peabody Picture Vocabulary Test* (PPVT-III; Dunn & Dunn, 1981). That is, it was assumed that if children were 1 standard deviation below the norm in English receptive language (even though Spanish receptive vocabulary may be in the average range), their language understanding during English reading instruction would not be in the normal range. Children with both English and Spanish receptive language scores above a standard score of 80 were designated as non-ELLs or balanced bilinguals.

In summary, children were designated as balanced bilingual at risk for RD (bilingual/RD), balanced bilingual but not at risk for RD (bilingual/NRD), children considered ELLs or nonbalanced bilinguals at risk for RD (ELL/RD), and children considered ELLs but not at risk for RD (ELL/NRD). At Wave 3, a comparison of the four groups yielded no significant differences related to gender, $\chi^2(3, N = 337) = 2.14$, $p = .90$; grade level, $\chi^2(6, N = 337) = 2.12$, $p = .89$; or participation in a government-sponsored free and reduced lunch program, $\chi^2(3, N = 337) = .52$, $p = .91$. The subgroups differed in terms of frequency of Spanish spoken in the home, $\chi^2(6, N = 337) = 19.68$, $p = .003$. Balanced and nonbalanced (ELL) bilingual children without RD were more likely to report that both English and Spanish were spoken in the home than balanced and nonbalanced bilingual children at risk for RD. The administration and psychometric features of the criterion and comparison measures are reported in detail in Swanson et al. (2012).

To classify the sample, norm-referenced measures in English and Spanish word identification and passage comprehension (WMLS-R [Woodcock et al., 2005]) and receptive vocabulary (PPVT [Dunn & Dunn, 1981] and *Test de Vocabulario en Imágenes* [TVIP; Dunn, Lugo, Padilla, & Dunn, 1986]) were administered. Also administered in English and Spanish were measures of the executive component of WM (Conceptual Span, Listening Span, Rhyming Span, and Updating; Swanson, 1992, 2013; Swanson et al., 2004; Swanson, Sáez, & Gerber, 2006), the STM (phonological loop) component of WM (Forward Digit Span, Backward Digit Span, Word Span, and Pseudoword Span; Swanson, 2014, Swanson & Beebe-Frankenberger, 2004); phonological processing (Segmentation and Blending [Leafstedt & Gerber, 2005; Swanson, Rosston, Gerber, & Solari, 2008]; Pseudoword reading task [Woodcock, 1998]), inhibition (random generation of numbers and letters; e.g., Towse & Cheshire, 2007; Swanson, 2014), naming speed (Rapid Naming of Digits and Letters; Wagner, Torgesen, & Rashotte, 2000), and oral language (The Morphological Closure subtest from the *Illinois Test of Psycho-linguistic Ability III* [ITPA; Gottardo, Yan, Siegel, & Wade-Woolley, 2001; Hammill, Mather, & Roberts, 2001] and *Expressive One-Word Picture Vocabulary Test–Spanish-Bilingual Edition* [EOWPVT-SBE; Brownell, 2001]). Two measures (Mapping/Directions Task and Visual Matrix Task; Swanson, 1992, 2013) were administered to assess the visual-spatial sketchpad component of WM. The *Colored Progressive Matrices* test (Raven, 1976) was administered to provide an indicator of nonverbal or fluid intelligence, and the Arithmetic subtest of the WRAT-3 (Wilkinson, 1993) was used as an indicator of math skill.

Table 1 provides an overview of the constructs measured and the sample reliability on individual measures. Table 2 shows the mean performance of the four subgroups on English classification measures as well as measures in which norm-referenced scores were available in both English and Spanish across all three testing waves.

Procedures

Children were tested individually and in groups, after informed consent was obtained for participation. For each testing wave, two sessions of individual testing were conducted, lasting 30 to 60 min for each session. Group testing occurred over the course of 2 consecutive days for approximately 1 hour each day. One of six presentation orders related to the individually administered tasks (WM, STM, phonological processing, and reading) were randomly assigned to each child. In addition, the presentation orders of Spanish and English tests were counterbalanced across all participants. For the group-administered tests (i.e., *Raven Colored Progressive Matrices* and WRAT-III Arithmetic subtest), the presentation order of English and Spanish measures for each type of task was also counterbalanced across groups. The raw scores for the total sample on individual measures at Wave 1 and the factor loading are reported in Appendix A of Swanson et al. (2012).

Design and Statistical Analyses

For the first testing wave, ELL children in Grades 1, 2, and 3 whose first language is Spanish were tested on the aforementioned battery of academic, language, and cognitive measures. For the second year of the project (Wave 2), those same participants were retested on the same measures in the

Table 1. Descriptive Information and Reliability of Measures Administered.

Construct	Task	Brief description	Sample reliability	
			English	Spanish
Literacy	WMLS-R word ID	Single word reading	0.92	0.92
	WMLS-R comprehension	Fill in the blanks in sentences	0.91	0.99
Fluid intelligence	Raven	Find missing piece of complex design	0.88	
Receptive vocabulary	PPVT or TVIP	Match vocabulary to picture	0.90	0.96
STM–phonological loop	Forward digit span	Recall sequentially ordered sets of digits	0.61	0.76
	Backward digit span	Recall digits in reverse order	0.80	0.90
	Word span	Recall sequentially ordered words	0.89	0.85
	Pseudoword span	Recall sequentially ordered sets of nonwords	0.90	0.87
Executive component of working memory	Conceptual span	Answer process questions and recall categories	0.90	0.85
	Listening sentence span	Answer process questions and recall words at the end of sentence	0.92	0.96
	Rhyming span	Answer process questions and recall acoustical-related words	0.92	0.96
	Updating span	Recall three-number sequence from varying sequence	0.94	0.92
Visual-spatial sketchpad	Matrix	Remember visual sequences within a matrix	0.92	
	Mapping and direction	Remember a sequence of directions on a map	0.93	
Phonological processing	Segmenting words	Separate and say a word in individual phonemes	0.90	0.94
	Segmenting nonwords	Separate and say a nonword in individual phonemes	0.96	0.91
	Blending words	Combine individual sounds together to say a word	0.85	0.89
	Blending nonwords	Combine sounds together to say a nonword	0.91	0.88
	Pseudoword reading	Single nonword reading	0.97	0.79
Inhibition	Random number	Write numbers in random order	0.80	0.89
	Random letter	Write letters in random order	0.87	0.86
Naming speed	CTOPP digits	Rapid naming of digits	0.92	0.98
	CTOPP letters	Rapid naming of letters	0.92	0.99
Oral language	ITPA–morphological closure	Fill in grammatically correct word	0.91	0.97
	EOWPVT-SBE	Provide word for picture	0.97	0.89
Math	WRAT-math	Arithmetic calculation	0.90	

Note. CTOPP = *Comprehensive Test of Phonological Processing*; EOWPVT-SBE = *Expressive One-Word Picture Vocabulary Test–Spanish-Bilingual Edition*; ITPA = *Illinois Test of Psycho-linguistic Ability III*; PPVT = *Peabody Picture Vocabulary Test*; Raven = *Raven Progressive Matrices*; TVIP = *Test de Vocabulario en Imagenes Peabody*; WMLS-R = *Woodcock-Muñoz Language Survey–Revised*; WRAT = *Wide Range Achievement Test.*

fall 1 year later. For Year 3 (Wave 3), participants who were in Grades 2, 3, and 4 of the previous year were again retested in the fall in Grades 3, 4, and 5. Thus, the design consisted of making three remeasurements of cross-sectional age groups so that overlapping measurements of older and younger participants were provided. Because children were nested within classrooms, the multilevel regression model included as random effects children's assignment to Waves 1, 2, and 3 reading classroom/teachers. However, it is also important to note that this cross-classification model (nested effects for Waves 1, 2, and 3; see Hox, 2010, chapter 9, for a review) for random effects at Wave 1 and 3 were not significant, and thus for parsimony, these random effects were dropped from the analysis.

Results

Table 2 shows the means and standard deviations on normed referenced measures of reading, vocabulary, math, and fluid intelligence for the total sample and the four subgroups.

Table 2. Norm-Referenced Scores for Children With and Without Reading Disability as a Function of Bilingual Proficiency.

	Total sample		Balanced bilingual				Nonbalanced bilingual (ELL)			
			RD		NRD		RD		NRD	
Variable	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Wave 1[a]										
E-WD ID[b]	102.39	14.91	85.04	13.16	110.52	10.22	83.91	10.80	103.93	8.14
E-Comp[b]	91.60	14.94	73.54	14.62	99.26	9.02	74.93	15.14	92.84	6.81
E-Vocabulary[b]	83.84	9.67	82.44	7.92	88.96	8.51	74.45	6.76	77.74	5.54
S-Vocabulary	82.01	16.65	90.04	16.08	88.24	16.57	70.33	10.11	71.64	9.52
Math	103.04	12.35	100.53	12.26	106.24	11.26	97.23	13.99	102.38	12.50
Fluid Intelligence[c]	59.53	22.25	50.53	18.14	63.46	22.77	54.04	21.70	58.76	21.56
S-WD ID	89.80	25.79	78.04	23.56	99.99	24.61	70.20	19.50	85.38	22.06
S-Comp	68.70	23.57	58.36	22.63	75.00	22.90	55.42	22.57	66.34	21.37
Wave 2[d]										
E-WD ID[b]	102.21	15.51	86.31	15.97	109.47	11.58	85.14	13.19	103.12	9.71
E-Comp[b]	94.95	13.36	84.10	18.20	100.21	9.76	82.10	13.55	94.06	8.81
E-Vocabulary[b]	85.89	11.06	80.90	11.97	89.78	9.86	78.02	12.16	82.61	9.42
S-Vocabulary	79.54	16.02	84.10	18.52	82.34	16.28	71.14	14.30	74.03	11.39
Math	99.97	11.47	96.51	10.23	102.93	11.64	93.47	10.18	100.77	10.54
Fluid Intelligence[c]	65.47	22.51	55.93	23.94	70.07	21.53	48.59	24.05	68.16	18.12
S-WD ID	92.43	25.39	80.83	21.85	101.19	24.90	71.84	16.33	89.43	21.12
S-Comp	69.85	20.83	61.66	20.28	75.81	18.70	56.37	22.40	68.84	18.73
Wave 3[e]										
E-WD ID[b]	99.73	16.72	86.55	15.29	107.39	14.21	83.12	15.59	99.20	10.04
E-Comp[b]	91.32	13.82	80.48	12.38	96.55	11.93	80.26	13.11	91.46	10.85
E-Vocabulary[b]	87.72	10.84	84.69	11.8	91.24	9.66	79.36	8.40	84.24	10.46
S-Vocabulary	78.16	17.32	82.71	17.55	81.53	17.94	66.12	11.45	72.71	13.47
Math	99.33	12.90	92.83	12.00	102.85	11.68	88.51	10.11	100.76	12.38
Fluid Intelligence[c]	66.54	22.85	62.02	22.02	70.46	22.27	56.50	23.71	65.04	22.46
S-WD ID	91.11	28.52	81.88	29.82	99.23	27.45	68.12	21.26	90.33	24.39
S-Comp	63.65	22.34	59.98	22.5	70.30	19.09	46.79	24.26	61.89	20.39

Note. Mean standard scores for classification measures across all three testing waves are in standard score units. Comp = Passage Comprehension subtest from *Woodcock-Muñoz Language Survey–Revised*; E = English; Fluid Intelligence = *Raven Progressive Matrices*; Math = Computation subtest from *Wide Range Achievement Test*; NRD = no reading disability; RD = reading disability; S = Spanish; Vocabulary = *Peabody Picture Vocabulary Test* (English) or the *Test de Vocabulario en Imagenes Peabody* (Spanish); WD ID = Letter Word Identification subtest from *Woodcock-Muñoz Language Survey–Revised*.
[a]Total sample: n = 450; balanced bilingual: RD n = 57, NRD n = 223; ELL: RD n = 55, NRD n = 115. [b]Classification measures used to split the sample. [c]Percentile score. [d]Total sample: n = 396; balanced bilingual: RD n = 48, NRD n = 209; ELL: RD n = 49, NRD n = 90. [e]Total sample: n = 337; balanced bilingual: RD n = 42, NRD n = 177; ELL: RD n = 42, NRD n = 76.

Data Preparation

*Confirmatory factor analysis.*Because we were not interested in the variance related to individual tasks but what was common amongst the observed variables, we tested whether our a priori categorization of the variables (i.e., phonological processing, WM, STM, naming speed, inhibition, and oral language) provided a good fit to the data (also see Swanson, Orosco, & Kudo, in press). The advantage of using these latent variables in our ability group classifications was that nonshared variance, including measures error, was extracted as error variance and not included in the scores. The separation by a language system was important, so we could assess whether individual differences that emerged were related to the ease of access within a particular language system (L1 or L2; see Note 1).

The factor structure shown in Appendix A of Swanson et al. (2012) provided a good fit to the data: Comparative Fit Index (CFI) = .92; RMSEA = .04 (90% CI: .031, .045); Bentler non-normed index (NNFI) = .90. Clearly, a second order model could have been tested that reflected constructs that overlapped between the languages (i.e., language-independent constructs; see Swanson et al., 2012, for a second order analysis at Wave 1); however, we were primarily interested in tapping individual differences in the accessing of information within the two language systems.

Based on the loadings, latent scores were computed by multiplying the *z* score of the target variable by the factor loading based on the total sample at Wave 1 (see Nunnally & Bernstein, 1994, p. 508, for the calculation procedures). Consistent with previous investigations of growth (e.g., Wilson et al., 2002), all measures at Wave 1 were scaled to have a mean of 0 and standard deviation of 1. Wave 2 and 3 measures were *z* scores based upon the means and standard deviations, as well as the factor weightings, of Wave 1. This was done because it was necessary to scale to *z* scores across the total sample so that all parameters were on the same metric, thus enabling meaningful comparisons across testing waves.

After establishing that performance on the latent measures followed a common line (intercept and slopes for overlapping ages were statistically comparable across the cohorts), we considered whether measures of WM contributed important variance to later L2 reading performance in the total sample (see Note 2). We now consider our first question.

Question 1

> Is there a significant relationship between components of WM and reading growth, and is such a relationship dependent on the type of reading task?

This analysis focused on the total sample and determined whether the contribution of WM growth to reading was isolated to comprehension or more broadly to both word identification and comprehension. Following standard multilevel latent growth modeling procedures (Singer & Willett, 2003), we modeled individual-specific intercepts, β0i, and the linear slope, β1i, in predictions of English word identification and passage comprehension. As shown in Table 3, Model 1 entered the continuous variables of English and Spanish vocabulary as well as the interaction between English and Spanish vocabulary in predictions of English reading. Significant main effects related to both measures in predictions of reading would suggest that children drew upon both language systems (i.e., a bilingual advantage), whereas an interaction would suggest dominance of one language system over another. Also included in the model were measures of phonological processing, naming speed, inhibition, measures of oral language (morphology and expressive vocabulary), and fluid intelligence. Although we expected oral vocabulary to account for significant variance, fluid intelligence was entered because of its close association with WM (Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Engle et al., 1999). In fact, some authors have assumed that WM and fluid intelligence measure the same construct (e.g., Kyllonen & Christal, 1990), and therefore, to examine whether WM uniquely tapped controlled attention, fluid intelligence (and STM in later modeling) was partialed out in the analysis (Conway et al., 2002).

Model 2 entered the measures related to WM. Of primary interest was whether the inclusion of WM variables provided a significantly better fit to the data than a model without those measures. A comparison of Models 1 and 2 for the criterion measures of word identification and passage comprehension are shown in Table 3. The top of Table 3 shows the fit indices for the likelihood value (deviance), Akaike's Information Criterion (AIC), and the Bayesian Criterion (BIC). Model 2 deviance values indicated a significantly better fit to the data than Model 1 for word identification, $\Delta\chi^2(10) = 54.9$ (2,063.2–2,008.3), $p < .001$, and passage comprehension, $\Delta\chi^2(10) = 87.3$ (2,008.3–1,921.0), $p < .001$, providing support for the notion that WM measures played a major role in the prediction of L2 reading performance beyond the contribution of phonological processing, naming speed, inhibition, and oral language measures.

Given that Model 2 provided a better fit to the data than Model 1, we next determined those parameters of WM that best predicted L2 reading performance. For word identification, the executive component of WM at Wave 1 and growth in the executive component of WM were the only components yielding significant parameters when compared to the other WM components. Of course, it is important to place these findings in context. Unique and significant predictions at Wave 1 also emerged for measures of English vocabulary and English phonological processing. Likewise, unique and significant predictions of word identification were found related to growth measures of English vocabulary, English phonological processing, Spanish naming speed, and fluid intelligence.

For passage comprehension, the English executive and a visual-spatial component of WM at Wave 1 and growth in the English executive, English phonological loop, and the visual-spatial component of WM each yielded significant parameters. Unique and significant predictions at Wave 1 also emerged for measures of English vocabulary, English phonological processing, English inhibition, and Spanish oral language measures. In addition, unique and significant predictions of passage comprehension were found related to growth in measures of English vocabulary, English phonological processing, Spanish naming speed, Spanish oral language, and fluid intelligence.

In summary, the results support the hypothesis that the executive component of WM within the L2 system was related to growth in both English word identification and passage comprehension. The results also show the models that included the WM components in their predictions of L2 reading provided an excellent fit to the data. An analogous measure to *R*2 was computed comparing the Model 2 to the unconditional means model (Model 1) using a formula by Snjiders and Bosker (1999, pp. 173–180). The *R*12 was computed by considering the residual variance and intercept variance. Model 2 for English word identification accounted for 19% of the explainable variance, *R*12 = (1 – [(.04 + .0005

Table 3. Hierarchical Linear Growth Model Predicting Word Identification and Passage Comprehension With and Without WM Components.

	Word identification				Passage comprehension			
	Model 1		Model 2		Model 1		Model 2	
Fit indices								
Deviance	2,063.2		2,008.3		2,008.3		1,921.0	
AIC	2,123.2		2,088.3		2,068.3		2,001.0	
BIC	2,191.9		2,179.9		2,137.1		2,092.7	
	Estimate	*SE*	Estimate	*SE*	Estimate	*SE*	Estimate	*SE*
Fixed effects								
Intercept	0.330**	0.08	0.39**	0.07	0.44**	0.07	0.48**	0.07
E-Vocabulary	0.001**	0.0001	0.0005*	0.0001	0.0004**	0.0001	0.0004**	0.0001
S-Vocabulary	0.006	0.004	0.004	0.004	−0.005	0.004	−0.005	0.004
Interaction	−0.0002	0.0001	−0.0001	0.0001	0.00002	0.0001	0.00002	0.0001
E-Phonological Processing	0.023**	0.003	0.02**	0.003	0.01**	0.003	0.013**	0.003
S-Phonological Processing	0.014**	0.003	0.01	0.003	0.0023	0.003	−0.0007	0.003
E-Naming Speed	−0.001	0.002	−0.002	0.002	0.0037	0.002	0.002	0.002
S-Naming Speed	0.004	0.003	0.002	0.003	0.0086	0.003	0.006	0.003
E-Inhibition	0.007	0.003	0.004	0.003	0.0099*	0.003	0.008*	0.002
S-Inhibition	0.001	0.003	0.0008	0.003	−0.0019	0.003	−0.00	0.003
S-Oral Language	0.006	0.003	0.003	0.002	0.009*	0.002	0.007*	0.002
Fluid Intelligence	0.001	0.001	0.001	0.001	0.003	0.001	0.002	0.0018
E–Short-Term Memory			0.004	0.004			0.0009	0.0042
S–Short-Term Memory			0.005	0.004			0.005	0.0044
E-WM			0.01**	0.003			0.01**	0.003
S-WM			0.0006	0.004			0.004	0.004
Visual-WM			0.0003	0.002			0.01**	0.003
Growth								
E-Vocabulary	−0.003**	0.0009	−0.003**	0.0009	−0.003**	0.001	−0.004*	0.0008
S-Vocabulary	−0.02	0.05	−0.0005	0.05	−0.03	0.05	−0.01	0.05
Interaction	0.001	0.001	0.0006	0.001	0.001	0.001	0.001	0.001
E-Phonological Processing	−0.32**	0.03	−0.25**	0.03	−0.32**	0.03	−0.24**	0.03
S-Phonological Processing	−0.11*	0.04	−0.09	0.04	−0.01	0.04	0.007	0.04
E-Naming Speed	0.010	0.04	0.03	0.04	−0.04	0.04	−0.004	0.04
S-Naming Speed	−0.21**	0.04	−0.17*	0.04	−0.19**	0.04	−0.14**	0.04
E-Inhibition	−0.06	0.04	−0.03	0.04	−0.12*	0.04	−0.08	0.04
S-Inhibition	0.01	0.04	0.03	0.04	0.03	0.04	0.06	0.04
S-Oral Language	−0.07	0.03	−0.05	0.03	−0.12**	0.03	−0.10**	0.03
Fluid Intelligence	−0.09*	0.02	−0.07*	0.02	−0.10**	0.02	−0.08**	0.02
E–Short-Term Memory			−0.14	0.05			−0.20**	0.05
S–Short-Term Memory			−0.01	0.05			−0.01	0.05
E-WM			−0.20**	0.05			−0.15**	0.05
S-WM			−0.04	0.07			−0.07	0.07
Vis-WM			−0.03	0.04			−0.13*	0.04
Random effects								
τ^2_{00}	0.05*	0.02	0.04*	0.02	0.01	0.01	0.007	0.009
τ^2_{01}	0.001	0.0003	0.0005	0.0003	0.0006	0.0003	0.0004	0.0003
τ^2_{02}	0.07	0.04	0.05	0.03	0.06	0.04	0.03	0.03
σ^2	0.38**	0.01	0.36**	0.01	0.37**	0.01	0.34**	0.01

Note. Deviance = −2 Log Likelihood; E = English; Interaction = English × Spanish vocabulary; Oral Language = syntax and expressive language; S = Spanish; Vis-WM = visual-spatial sketchpad; WM = executive components of working memory.
$^*p < .01$. $^{**}p < .001$.

+ .03 + .36)/(.05 + .001 + .07 + .38)] × 100, whereas the Model 2 for passage comprehension accounted for 14% of the explainable variance, $R12 = (1 - [(.007 + .0004 + .03 + .34)/(.01 + .0006 + .06 + .37)] \times 100$.

Subgroup Comparisons

This analysis considered whether growth in WM varied as a function of risk for RD. Consistent with our Wave 1 study (Swanson et al., 2012), the sample was divided based on the aforementioned cut-off scores into two language and two reading groups. The means and standard deviations for performance on manifest and latent variables (in *z* scores) as a function of each testing wave and ability group are reported in Appendix A. The general trend was that children not at risk for RD scored higher than those at risk, balanced bilingual children outperformed nonbalanced bilingual (ELL) children, and scores were higher in Wave 3 when compared to Waves 1 and 2. As shown in Appendix A, when Wave 1 was subtracted from Wave 3, larger difference scores occurred on measures of reading and language than on measures of cognition. We now addressed the second question of our study.

Question 2

> Are there growth differences in the executive component of WM as a function of children at risk and not at risk for RD who also vary in bilingual proficiency, and if so, do these differences merely reflect an artifact of STM storage and/or related cognitive processes?

To answer this question required three steps. First, ability groups were compared across several cognitive measures across the three testing waves. Of interest was whether there was a qualitative change in WM in performance when compared to other processes over the three testing waves. That is, was performance over time (testing waves) more likely to interact with some components of WM when compared to other components or cognitive processes? Second, growth estimates were computed across the various cognitive measures. Previous work has already established that ability group differences occur across a broad range of cognitive measures at Wave 1 (Swanson et al., 2012), but whether ability group differences can be tied to actual growth in WM or growth in other related cognitive processes has not been established in the literature. Finally, ability groups were compared on the executive component of WM when STM and related phonological processes were partialled out in the mixed regression analysis. Such an analysis that compared regression models with and without the covariate partial out allowed us to determine if ability group differences in performance on the executive component of WM were mediated by a phonological storage system.

Qualitative changes. The analysis included a 2 (Language Status: Balanced vs. Nonbalanced Bilinguals) × 2 (Risk Group: Children at Risk vs. Not at Risk for RD) × 3 (Testing Waves 1, 2, and 3) MANCOVA, with repeated measures on the last factor. In describing the comparisons, children labeled as nonbalanced bilinguals will be referred to as ELLs to simplify the presentation of results. Because slight differences in chronological age and fluid intelligence occurred between the subgroups at Wave 1, these measures served as covariates in the analysis. This analysis excluded those children with missing values across the testing waves (missingness will be addressed in the next analysis). The *F* ratios for each latent (i.e., cognitive measures) and manifest variable (i.e., reading measures) are shown in Table 4. Given the number of comparisons, the alpha level was set to .001.

There were two important findings. First, no significant interaction related to testing wave occurred as a function of bilingual status or reading ability on any of the reading, language, and cognitive measures. Thus, it can be assumed the classification of RD that occurred at Wave 1 was maintained across all three testing waves. As expected, significant main effects occurred for testing waves (df = 2, 690) on all English measures. Improvements in performance also occurred on some of the Spanish measures related to reading, phonological processes and oral language. However, the important finding was that the classification status that emerged in Wave 1 remained stable across Waves 2 and 3.

Second, no significant Bilingual Status × Read Group interactions occurred. Rather, the results yielded only significant main effects for the language status factor (df = 1, 345). Balanced bilingual children outperformed ELL children on English and Spanish vocabulary measures. Balanced bilingual children also significantly outperformed ELL children on Spanish measures of WM and phonological processing. Likewise, children not at risk for RD significantly (df = 1, 345) outperformed children at risk for RD across a wide array of measures. As expected, significant performance advantages occurred for children without RD when compared to children with RD on English and Spanish reading measures. In addition, a performance advantage occurred for children without RD when compared to children with RD across a broad array of English (WM, STM, phonological processing, oral language, and naming speed) and Spanish measures (WM, STM, and phonological processing) when compared to children with RD.

Interestingly, as shown in Table 4, the *F* ratios were not significant for the main effects of testing wave on measures of the visual-spatial sketchpad. As will be shown in later growth modeling, the lack of a significant effect for visual WM across the testing waves was due to the use of Raven scores, which served as a covariate in the analysis.

In summary, the results revealed no significant interactions related to testing waves. Thus, there was no evidence to suggest that qualitative differences related to ability

Table 4. *F* Ratios for the Language × Risk × Testing Wave MANCOVA as a Function of English and Spanish Latent Measures.

Measure	Bilingual	RD	Wave	BI × RD	BI × Wave	RD × Wave	Three-way
Achievement and language							
Word identification[a]							
English[a]	0.45	118.80***	87.26***	4.30	8.01	0.76	1.20
Spanish	10.09	27.52***	16.28***	1.49	1.89	1.72	1.42
Passage comprehension							
English[a]	0.03	128.75***	74.95***	6.83	2.37	4.11	1.35
Spanish	6.15	28.44***	11.33***	1.31	3.55	3.96	1.01
Vocabulary							
English[a]	22.72***	9.09	38.16***	0.66	6.43	1.52	3.24
Spanish	25.57***	0.03	4.10	0.68	6.37	3.06	0.15
Cognitive							
Short-term memory							
English	0.24	22.95***	13.38***	1.55	0.11	2.11	0.63
Spanish	8.41	16.84***	15.30***	0.02	0.57	0.59	0.96
Working memory							
English	5.76	22.05***	10.23***	2.09	0.70	2.31	2.14
Spanish	11.70***	12.54***	3.59	0.02	0.40	0.54	0.75
Visual-spatial sketchpad	0.29	0.87	1.22	0.01	0.08	1.12	1.76
Naming speed							
English	2.93	16.13***	25.59***	5.29	0.88	1.22	1.14
Spanish	3.43	5.85	3.05	1.18	2.36	0.15	1.52
Phonological processing							
English	8.70	51.96***	18.90***	1.22	0.84	2.18	1.75
Spanish	13.54***	35.82***	9.48***	0.25	0.40	1.82	0.92
Oral language							
English	3.65	30.58***	75.38***	6.61	2.08	0.40	0.73
Spanish	9.75	2.25	20.19***	0.15	1.70	1.69	2.34
Inhibition							
English	1.51	10.74	11.37***	0.00	1.34	0.02	0.25
Spanish	1.69	6.02	6.03	0.04	2.93	0.35	2.58

Note. BI = bilingual; Bilingual = Bilingual vs. ELL; RD = children at risk and not at risk for RD; Wave = three testing waves.
[a]Classification measure.
***$p < .001$.

group (interactions) occurred across the testing waves. More important, the cognitive differences that occurred between ability groups at Wave 1 were maintained across the three remaining testing waves.

*Growth comparisons.*Although no significant ability group interactions occurred across testing waves, it was of interest to determine if variations occurred between ability groups in terms of growth (slopes). Table 5 summarizes the fixed effects related to intercept and growth estimates for the ability groups across the classification and related achievement and language measures. Table 6 summarizes the intercept and growth estimates for the cognitive measures. For these analyses, the intercept values were centered at Wave 3, because significant Wave 1 group differences were already established in our previous analyses. Consistent with cohort-sequential studies, the slope was set at the age in which the cohorts overlapped (Mehta & West, 2000; see p. 29 for a discussion). In this case, the three cohorts overlapped at Grade 3 or age 9.

Both tables show the post hoc Tukey tests if the *F* ratios comparing the four groups were significant. Given the number of comparisons between groups (e.g., $df = 3$, 1,061 to 1,158) shown in Tables 5 and 6, the alpha level was again set to .001.

To interpret the findings, recall that the latent measures for the intercepts at Wave 3 reflected *z* scores based on means and standard deviations in performance at Wave 1. For example, in Table 5, balanced bilingual children at risk for RD yielded an English word identification *z* score of –.03 at Wave 3, whereas balanced bilingual children not at risk for RD on the same measure yielded a *z* score of 1.36. However, both groups yielded comparable growth rates.

Table 5. Intercepts at Wave 3 and Growth Parameters (z Scores) for Language and Achievement Measures as a Function of Ability Groups Defined at Wave 1.

Variable: Language and achievement measures	Balanced bilingual				Nonbalanced bilingual (ELL)					
	At risk for RD		Not at risk for RD		At risk for RD		Not at risk for RD			
	Estimate	*SE*	Estimate	*SE*	Estimate	*SE*	Estimate	*SE*	*F* ratio	Tukey[a]
Word identification										
E-Intercept[b]	−0.03	0.07	1.36	0.05	−0.08	0.06	0.90	0.06	262.68***	2 > 4 > 1 = 3
E-Growth[b]	0.03	0.003	0.04	0.002	0.03	0.004	0.04	0.003	2.21	
S-Intercept	−0.04	0.10	0.99	0.08	−0.15	0.09	0.48	0.09	104.01***	2 > 4 > 1 = 3
S-Growth	0.02	0.004	0.03	0.002	0.02	0.004	0.02	0.003	2.99	
Passage comprehension										
E-Intercept[b]	0.31	0.07	1.35	0.04	0.26	0.06	1.02	0.05	157.28***	2 > 4 > 1 = 3
E-Growth[b]	0.04	0.004	0.03	0.003	0.05	0.004	0.04	0.003	4.34	
S-Intercept	−0.03	0.12	1.07	0.09	−0.12	0.11	0.58	0.1	89.35***	2 > 4 > 1 = 3
S-Growth	0.02	0.005	0.03	0.002	0.02	0.005	0.03	0.003	4.82	
Vocabulary										
E-Intercept[b]	0.91	0.08	1.58	0.05	0.45	0.07	0.91	0.06	92.70***	2 > 4 > 1 = 3
E-Growth[b]	0.04	0.004	0.05	0.002	0.05	0.004	0.06	0.003	4.01	
S-Intercept	0.65	0.09	0.73	0.06	0.05	0.08	0.31	0.07	29.42***	2 = 1 > 4 > 3
S-Growth	0.02	0.004	0.02	0.003	0.02	0.004	0.03	0.003	1.88	

Note. E = English; NRD = no reading disability; RD = reading disability; S = Spanish.
[a]Post hoc comparisons included four comparison groups: 1 = balanced at risk for RD, 2 = balanced not at risk for RD, 3 = nonbalanced at risk for RD, 4 = nonbalanced not at risk for RD. [b]Classification measures at Wave 1.
***$p < .001$.

Balanced bilingual children at risk for RD gained .03 units per testing wave, whereas balanced bilingual children not at risk RD gained .04 units per testing wave in English word identification.

In general, the results shown in Tables 5 and 6 indicated that significant subgroup differences were isolated primarily to performance level (intercepts) at Wave 3 but not growth rates (slopes). The only significant growth parameters that emerged between the reading groups were related to performance on the English WM measures. In this case, children with RD showed significantly lower growth rates than children without RD.

*Regression-based comparisons.*The previous analysis found a significant relationship between growth in the executive component of WM and reading ability. However, there may be confounds in this comparison related to the child's dominant language. Further, the previous analysis failed to establish that the executive component of WM, independent of the phonological storage system, underlies ability group differences. To address this issue, we implemented a regression model outlined by Stanovich and Siegel (1994) that allowed for the entry of nonorthogonal contrast variables simultaneously into a regression model (see pp. 27–30 for a rationale). Further, the model also allowed us to partial out the linear trends related to the phonological system. Thus, along with contrast variables, the linear trends of L1 and L2 phonological processes and STM were partialed from the criterion (WM) variable.

The first contrast variable compared children not at risk for RD (coded +1) and children at risk for RD (coded −1). The second contrast compared ELL children (coded +1) and balanced bilingual children (coded −1). The third contrast variable compared balanced bilingual children at risk for RD (coded +1) and ELLs at risk for RD (coded −1; remaining groups = 0). The fourth contrast variable compared children lower in Spanish than English (coded +1 for children who scored higher in Spanish than English and coded −1 for children who scored lower in Spanish than English). Thus, instead of just relying on the cut-off standard score of 90 in English vocabulary discussed earlier, we also coded for the comparison of children's highest proficiency in either language.

The outcomes for the regression modeling for predicting performance on the executive component of WM at Wave 3 are shown in Table 7. The intercept represented the average *z* score for the total sample at Wave 3. The variable "Age-C" (cross-sectional age effects) captured the age-related variance related to WM at Wave 1 (or stated differently the cohort effects for WM). The variables below this entry reflected the covariates at Wave 1 (i.e., those variables significantly related to the WM

Table 6. Intercept at Wave 3 and Growth Parameters for Cognitive Measures as a Function of Ability Groups Defined at Wave 1.

	Balanced bilingual				Nonbalanced bilingual (ELL)					
	At risk for RD		Not at risk for RD		At risk for RD		Not at risk for RD			
Variable	Estimate	*SE*	Estimate	*SE*	Estimate	*SE*	Estimate	*SE*	*F* ratio	Tukey[a]
Phonological Loop-STM										
E-Intercept	0.11	0.03	0.38	0.02	0.08	0.03	0.26	0.02	38.54***	2 = 4 > 1 = 3
E-Growth	0.01	0.002	0.01	0.001	0.01	0.002	0.01	0.001	0.68	
S-Intercept	0.17	0.03	0.31	0.02	0.01	0.03	0.18	0.03	34.37***	2 > 4 = 1 > 3
S-Growth	0.01	0.001	0.01	0.001	0.01	0.001	0.01	0.001	2.19	
WM-Executive Component										
E-Intercept	0.03	0.04	0.40	0.02	−0.004	0.03	0.20	0.03	69.49**	2 > 4 > 1 = 3
E-Growth	0.01	0.002	0.01	0.001	0.008	0.002	0.02	0.001	9.27***	4 = 2 > 1 = 3
S-Intercept	0.18	0.03	0.33	0.02	0.03	0.03	0.20	0.02	43.28**	2 = 4 = 1 > 3
S-Growth	0.01	0.001	0.01	0.001	0.01	0.001	0.01	0.001	1.44	
Visual-spatial working memory										
Intercept	0.33	0.04	0.46	0.03	0.29	0.04	0.40	0.03	6.97**	2 = 4 > 1 = 3
Growth	0.01	0.001	0.02	0.001	0.02	0.001	0.02	0.001	0.30	
Phonological processing										
E-Intercept	−0.001	0.05	0.54	0.04	−0.09	0.05	0.30	0.04	82.72***	2 > 4 > 1 = 3
E-Growth	0.01	0.003	0.01	0.002	0.01	0.003	0.02	0.002	0.09	
S-Intercept	0.03	0.05	0.52	0.04	−0.07	0.05	0.30	0.04	71.52***	2 = 4 > 1 = 3
S-Growth	0.01	0.002	0.01	0.002	0.01	0.001	0.02	0.002	0.09	
Naming speed										
E-Intercept	0.12	0.04	0.32	0.02	0.15	0.03	0.27	0.03	9.52***	2 = 4 > 1 = 3
E-Growth	0.02	0.002	0.01	0.001	0.01	0.002	0.01	0.001	3.22	
S-Intercept	−0.03	0.03	−0.11	0.02	0.22	0.03	−0.07	0.02	6.43***	3 > 1 = 4 = 2
S-Growth	0.02	0.001	0.02	0.001	0.02	0.001	0.02	0.001	1.20	
Inhibition										
E-Intercept	0.12	0.04	0.29	0.03	0.15	0.04	0.33	0.03	10.82***	2 = 4 > 1 = 3
E-Growth	0.01	0.001	0.01	0.001	0.01	0.001	0.01	0.001	0.55	
S-Intercept	0.03	0.04	0.21	0.02	0.12	0.03	0.22	0.03	9.01***	2 = 4 > 3 = 1
S-Growth	0.01	0.001	0.01	0.001	0.001	0.001	0.01	0.001	1.77	
Oral language										
E-Intercept	0.40	0.05	1.07	0.03	0.29	0.04	0.68	0.04	124.25**	2 > 4 >1 > 3
E-Growth	0.03	0.001	0.03	0.001	0.03	0.001	0.04	0.001	1.94	
S-Intercept	0.43	0.06	0.49	0.05	0.06	0.06	0.28	0.05	25.74***	1 = 2 > 4 > 3
S-Growth	0.02	0.003	0.02	0.002	0.01	0.002	0.02	0.002	3.22	

Note. RD = reading disability; NRD = no reading disability; E- = English; S- = Spanish; RD = reading disability.
[a]Post-hoc comparisons included 4 comparison groups: 1 = Balanced at risk for RD, 2 = Balanced not at risk for RD, 3 = Non-balanced at risk for RD; 4 = Non-balanced not at risk for RD.
**$p < .01$. ***$p < .001$.

cross-sectional effect). The variable "growth" was the slope for WM at the point in which the cohorts overlapped (Grade 3). The variables below this entry reflected the relationship between the slopes for each covariate and the slope for WM.

Table 7 shows the parameters of the unconditional means model and three conditional regression models. The Unconditional Means Model included estimates for both cross-sectional (between age effect of WM) and growth (within age effects of WM) effects. Conditional Model 1 added to the model the covariates of phonological processing and STM. Conditional Model 2 added to Model 1 the ability group contrast variables. Conditional Model 3 replaced the contrast variables with the continuous variables of English reading and English and Spanish vocabulary.

To interpret Table 7, consider Conditional Model 1 for the fixed effects. As shown, the intercept (.18) reflected the sample average *z* score for English WM at Wave 3. As shown in Conditional Model 1, the covariates of English STM (.01) and Spanish STM (.008) at Wave 1 were significantly related to the cross-sectional effects of English WM performance. Because these covariates were grand mean

Table 7. Hierarchical Regression Model Predicting the Executive Component of English Working Memory.

	Unconditional model		Model 1		Model 2		Model 3	
Fixed effects	Estimate	*SE*	Estimate	*SE*	Estimate	*SE*	Estimate	*SE*
Intercept	0.19***	0.05	0.18**	0.04	0.17**	0.04	.19**	0.04
I. Age-C	0.002	0.002	0.003	0.002	0.004	0.002	0.004	0.002
Covariates								
E-Phon			0.004	0.001	0.002	0.002	0.001	0.002
S-Phon			0.001	0.001	0.0007	0.002	0.002	0.001
E-STM			0.01**	0.002	0.009**	0.002	.009**	0.002
S-STM			0.008**	0.002	0.007**	0.002	.008**	0.002
RD vs. NRD					0.25**	0.04		
ELL vs. Bilingual					−0.003	0.002		
ELL-RD vs. Bilingual-RD					−0.004	0.002		
Spanish > English					0.0005	0.0008		
Reading							.12**	0.02
E-Language							0.002	0.009
S-Language							−0.003	0.009
Language × Reading							0.0002	0.0008
II. Growth	0.11***	0.03	0.06	0.02	0.06	0.03	.07*	0.03
Covariates								
E-Phon			−0.07**	0.01	−0.07**	0.02	−0.05**	0.02
S-Phon			0.002	0.01	0.008	0.02	0.004	0.02
E-STM			−.08**	0.02	−.08**	0.02	−0.07**	0.02
S-STM			−0.03	0.02	−0.03	0.02	−0.03	0.02
RD vs. NRD					0.10**	0.03		
ELL vs. Bilingual					0.02	0.02		
ELL-RD vs. Bilingual-RD					0.01	0.02		
Spanish > English					0.001	0.007		
Reading							0.03*	0.01
E-Language							−0.01	0.007
S-Language							−0.0005	0.008
Language × Reading							−0.005	0.006
Random effects	Variance	*SE*	Variance	*SE*	Variance	*SE*	Variance	*SE*
Age-C	0.0002***	0.00002	0.0001*	0.00002	0.00008*	0.00001	0.0002***	0.00002
Growth	0.006***	0.002	0.001	0.001	0.0006	0.001	0.006***	0.002
Residual	0.07***	0.005	0.07**	0.004	0.07**	0.004	0.07***	0.005
Deviance	628.8		477.9		432.8		382.5	
AIC	642.8		507.9		478.8		428.5	
BIC	670.9		567.9		570.9		520.4	

Note. AIC = Akaike's Information Criterion; BIC = Bayesian Criterion; Contrast 1 = RD vs. non RD; Contrast 2 = ELL vs. Balanced Bilingual; Contrast 3 = ELL RD vs. Balanced Bilingual RD; Contrast 4 = Higher Spanish vs. English; E = English; Language = vocabulary; NRD = no reading disability; Phon = phonological processing; RD = reading disability; Reading = combined English word identification and passage comprehension; S = Spanish; STM = phonological loop or short-term storage.
**p* < .01. ***p* < .001. ****p* < .001.

centered at Wave 1, the results can be interpreted as suggesting that children who differed by 1 unit on the English STM differed by .01 units in the cross-sectional effects of English WM at Wave 1.

In terms of growth (slope), the results in Table 7 show that only the covariates of English phonological processing growth (estimate = –.07) and English STM growth were significantly related to growth in English WM. These results suggested that growth on the measure of English STM (estimate = –.08) was significantly related to growth in English WM performance. The negative coefficients indicated that the relationship between STM growth and WM growth was increasingly diminished as WM growth increased.

Conditional Model 2 entered the classification measures as contrast variables. As shown, the contrast comparing children identified as at risk and those not at risk of RD based on a cut-off score was significantly related to WM cross-sectional and growth effects (estimate = .10). None of the other contrast variables were significant. Conditional Model 3 entered the classification measures as continuous variables. Also entered in the analysis was children's proficiency on the Spanish vocabulary measures. As found in Model 2, the classification measure related to reading at Wave 1 was significantly related to the cross-sectional and growth effects of WM.

The important findings were that both Model 2 (contrast variables) and Model 3 (continuous variables) provided a better fit to the data when compared to the Unconditional Means Model and Conditional Model 1. Deviance, AIC, and BIC values were lower in Model 3 when compared to the previous models, suggesting a better fit to the data. However, the patterns were not that much different in terms of the significant relationship between RD classification and WM cross-sectional and growth effects in terms of power (Type II error). In addition, because the variance related to the random effects for Model 3 was comparable to Model 2, the amount of explainable variance between the two models (when compared to Model 1) was comparable. Based on the assumption that when one or more predictors (explanatory variables) are introduced into the conditional model, the reductions in the magnitude of the various components when compared to the Unconditional Means Model are analogous to effect sizes (Snijders & Bosker, 1999), we infer the two models were comparable in terms of effect sizes.

In summary, children identified as at risk for RD by either using dichotomous or continuous measures experienced difficulties in English WM growth when measures of phonological processing and STM were partialed from the analysis.

Discussion

The purpose of this study was to examine the relationship between growth in the executive component of WM and growth in L2 reading within a heterogeneous sample of English language learners who vary in reading and language proficiency. The results showed that growth in the executive system of WM contributed unique variance to growth in English word identification and passage comprehension. These findings occurred when the competing variables of phonological processing, naming speed, inhibition, vocabulary, visual-spatial sketchpad, and fluid intelligence were entered into the growth model. These findings are consistent with other studies showing that performance related to specific components of WM are significantly related to later L2 reading performance (e.g., Swanson et al., 2006) but extend these earlier findings by showing that actual growth in specific components of WM was related to individual growth in L2 reading. We will now address the two questions that directed this study.

Question 1

The results shown in Table 3 indicated that WM variables provided a better fit to the data when they were included in the growth modeling than when left out (see Table 3). This finding coincides with earlier results showing a significant relationship between WM and L2 reading (Swanson et al., 2004) but extends these findings to show that growth on such measures may underlie some of the difficulties in terms of normative growth in L2 reading found in an ELL sample. We expected, however, the influence of the executive component of WM to be isolated to the more complex activities, such as reading comprehension, rather than word identification. Instead, growth in the executive component was related to both L2 word identification and passage comprehension. Thus, the executive processes related to WM can be viewed as providing resources to lower order skills, such as word identification, as well as to more complex L2 activities, such as reading comprehension.

Although our findings are in line with other studies, we can only speculate on why growth in the executive component of WM had a general influence across L2 reading measures. One straightforward explanation is that poor word recognition underlies poor comprehension. Initially, we discounted this interpretation because the normed-referenced scores on word identification scores were substantially higher than passage comprehension scores across all testing waves (see Table 2). In fact, the mean English passage comprehension scores hovered around the 25th percentile (standard score of 90) across all testing waves. However, it is possible there is a monitoring process in which the relationship between the executive component of WM and comprehension is due to the intelligent use of strategies that trade off between comprehension and word-recognition processes. Quite simply, the link between comprehension skill and WM is also mediated by those processes related to word recognition skills. To support this model, we would expect that processes clearly related to word recognition growth would be comparable to those of passage comprehension. This inference finds support when examining the growth parameters in Table 3. Common processes that predicted growth in both English word recognition and comprehension were English vocabulary, English phonological processes, Spanish naming speed, and fluid intelligence. Thus, we assume the relationship between the executive component of WM with both reading measures is related to monitoring some of the same processes.

The results do raise the question, however, as to why English WM (and not Spanish WM) predicted L2 reading. Previous studies have shown the both English and Spanish

WM load on a common latent factor (e.g., Swanson et al., 2004, 2012). In addition, a previous study (Swanson, 2014) has shown no interaction between Spanish and English WM in predictions of L2 reading, suggesting the executive system of WM acts independent of cross-language skills. Thus, we would not argue that English and Spanish WM tasks are tapping different systems. Rather, latent measures were created within both language systems in the present study to assess the ease of access to the executive component within a language system. Our findings related to English WM are consistent with cross-language studies (Costa & Santesteban, 2004; Kroll, Bobb, & Wodniecka, 2006) that have found participants relatively proficient in L1 and L2 (i.e., bilinguals) are able to achieve a language-specific processing "without" competition from their L1 language. Thus, for those children who are becoming increasingly proficient in their second language, the intention to activate the intended or targeted language suffices to restrict the role of WM to the target language (L2, English in this case). Our findings also align with the notion that greater WM capacity is more likely to yield a greater ability to avoid distraction (e.g., Engle, 2002), and therefore, L1 WM does not distract from the contribution of L2 WM within the targeted language system (L2 reading in this case).

Question 2

The general pattern in the repeated measures analysis (RMANCOVA), across all three waves, was that children with RD were at a significant disadvantage at each testing wave across several academic and cognitive domains when compared to children without RD. This was an expected finding and was consistent with studies showing that the same cognitive dimensions of RD found in monolingual samples matched closely with the cognitive dimensions found in ELL samples (e.g., Lipka & Siegel, 2007). However, what was unique in our findings was that no overall significant interaction emerged as a function of language status (balanced bilingual vs. ELL) for children with RD (see Table 4), suggesting that the pattern of cognitive performance found within the ELL sample (nonbalanced bilinguals) was statistically comparable to the balanced bilingual sample. Previous studies have compared ELL or bilingual children to monolingual children on measures reflective of one language system (i.e., English); seldom have comparisons been made across the language systems. Thus, our results extend this earlier research on cognitive deficits across two language systems to children operationally defined as RD.

We were primarily interested in determining whether executive processing differences attributed to children with RD in previous work (Swanson et al., 2006) were merely an artifact of not controlling for phonological STM storage or related phonological processes. As shown in our growth modeling (see Table 7), however, reading skill predicted English WM when measures of STM and phonological process were partialed in the analysis. The significant parameters related to the reading ability on cross-sectional and growth effects in the executive component of WM were found regardless of whether RD was treated as a contrast or continuous variable. This finding is important, as RD is viewed as a dimensional construct (a correlated continua of severity), suggesting that the categorical approach to RD is merely an artifact of the cut-off point (see Branum-Martin et al., 2013, for discussion). However, few studies have compared differences among classification groups on cognitive measures when the assumed variable underlying this relationship has been partialed from the analysis. Because the two approaches yielded comparable outcomes in terms of the significant relationship between WM and reading, we assumed that the significant relationship between reading proficiency and WM was not necessarily an artifact of the classification process.

Finally, we found RD differences in growth were isolated to the executive component of English WM. Although several differences at Wave 3 occurred between the subgroups in terms of level of performance across a number of latent measures of cognition and language, the only significant slope differences to emerge between the RD groups was related to the executive component of WM. That is, except on measures of the executive component of WM, linear growth parameters were not that different between children at risk or not at risk for RD across language, achievement, and cognitive domains.

Implications

What are the theoretical implications of the findings? We find a major cognitive component that underlies growth in L2 reading is growth in the executive component of WM. Thus, the influence of executive component WM on L2 processing is not merely a manifestation of individual differences in a phonological storage system. However, the question emerges as to whether the residual variance attributed to WM and L2 processing reflects controlled attention, a domain general attentional resource involved in the activation of information from LTM, a general monitoring system that coordinates the flow of information but draws from specialized storage systems, or a limited capacity resource that supports both processing and storage in a domain-specific system.

To answer this question, let us first consider the results in Table 3. English verbal forms of processing efficiency (naming speed, phonological processing, and inhibition) did not adequately account for or eliminate the influence of growth in WM when predicting growth in L2 reading. More important, given that the random generation task, as a measure of inhibition, did not eliminate the contribution of this residual variance to L2 processing, we tentatively concluded that some yet-to-be-specified aspects of controlled attentional processing played an important predictive role in L2 processing. Although data are lacking on all the components of executive processing (e.g., updating, task shifting, and inhibition; Miyake, Miyake, Friedman, Emerson, Witzki, & Howerter, 2000), we were able to separate out attention control as defined by Engle et al. (1999) and inhibition related to competing languages.

What are the practical implications? The most troublesome education implication was the finding that stable individual differences emerged in reading and cognitive outcomes as a function of reading and language proficiency. The results suggested that these children grow at similar rates in reading and cognitive skill as a function of formal schooling across the testing waves. Thus, schooling neither narrows the achievement gap within the sample nor exacerbates it. Although we did find that the executive component of WM was incrementally important in distinguishing children at risk and not at risk for RD, it does appear that when taking the findings altogether that some of the risk factors identified in the first testing wave were maintained 3 years later. We did not find that those children who were initially behind (those at risk for RD) fall further behind (significantly lower slopes), as one would predict related to the Matthew effect. Rather, the growth parameters (slopes) appeared to be quite similar across the four groups.

Limitations

There are at least four limitations to this study. First, because the majority of the sample (>95%) was participating in the federal free and reduced lunch program, we did not have enough variance to assess the role of socioeconomic status (SES) in the performance outcomes. In addition, we did not compare second language learners from other ethnic groups. Thus, the slopes cannot be generalized across SES or ethnic groups. Clearly, children with greater resources in the home (e.g., access to books) would have a positive influence on reading growth. This could not be captured within our data set.

Second, we did not take into consideration the influence of the child's second language exposure to their first language proficiency. Although this study is unique in exploring simultaneously the links between cognitive processes in both languages, it is important to highlight that reading instruction was in the child's second language. Previous research has delineated differences between bilingual children (e.g., Cummins, 1981) and suggests that bilingual children vary in their mastery level of each language. In addition, we found that English vocabulary played a major role in predictions of reading (see Table 3), whereas a Spanish vocabulary did not. In addition, as shown in Table 4, bilingual status was only important on two of the Spanish cognitive measures (WM and phonological processing), and therefore, we cannot assess the additive advantage of bilingual status on reading and cognitive performance in our low SES sample, nor can we generalize our findings to middle-class samples.

The results do raise the question, however, as to the role of phonological processing and vocabulary as mediators of the relationship between WM and L2 reading. The candidates most often referred to in the literature as potentially underlying risks for RD are phonological processes and oral language (e.g., see Farnia & Geva, 2011, for a review). There is considerable evidence that phonological processing and vocabulary are major cognitive determinants of word reading skills, especially in the early phases of learning (National Reading Panel, 2000). Cross-cultural linguistic studies have demonstrated that in elementary grades, phonological awareness (e.g., Dickinson, McCabe, Clark-Chiarelli, & Wolf, 2004; Gottardo et al., 2008) and vocabulary development (e.g., Kieffer & Lesaux, 2012; Ordóñez, Carlo, Snow, & McLaughlin, 2002) correlate with L2 (English) reading outcomes. Our findings are consistent with these studies. Specifically, Model 1 reported in Table 3 showed that English vocabulary and English phonological processing uniquely predict L2 reading proficiency. However, Table 3 also shows that when entering WM into the regression model, the executive component of WM contributed its own unique variance independent of the contribution of phonological processing and vocabulary. Thus, we would argue that the executive component of WM plays just as an important role as vocabulary and phonological processing in predictions of L2 literacy. However, it is important to note in our predictions of literacy, we did not partial out the effects of word identification on passage comprehension. This was because of the high correlation between the two reading measures.

Third, an adequate account for the outcome for why the visual-spatial component of WM predicted passage comprehension is unclear. That is, growth in the visual-spatial sketchpad was implicated in the regression analyses in predicting passage comprehension but not word identification. Although some studies have suggested the visual-spatial sketchpad may serve as a compensatory process when verbal skills are low for poor readers (e.g., McNeil & Johnston, 2008), we expected the visual-spatial sketchpad to play a minor role in performance outcomes when fluid intelligence was entered into the analysis. This was not the case. It is possible the visual-spatial sketchpad shares some unique variance with the executive system (cf., Friedman & Miyake, 2000), as it emerged as a significant covariate in predicting English comprehension. Therefore, performance on this measure may be more in line with the executive component of WM than to a visual-storage system.

Finally, and most important, was that we assessed the outcomes of reading instruction in the children's second language. Reading instruction within our sample may be characterized as reflecting extensive instruction in L2 phonological skill building. More importantly, children learned to read and write in their second and not their first language. Therefore, generalization of the present findings to samples of children who are fully bilingual is questionable.

Summary

Taken together, we interpret our findings as suggesting that growth in L2 reading is directly related to growth in the various components of the WM system. However, these components (phonological loop, central executive) appear to act somewhat independent of skills in phonological processing, naming speed, inhibition, and vocabulary. The current growth modeling supported the notion that growth in the executive component of WM was related to growth in L2 word identification and reading comprehension. Obviously, these are not the only variables that play a major role in accounting for reading growth in ELL children, but they do suggest that their role is not secondary to such measures as phonological awareness and oral language. No doubt, future research must focus on the interaction between executive and phonological components of memory during the act of reading in English learners across a broad age span to disentangle the alternative interpretations of the results.

Appendix

Table A1. Mean z Scores for Manifest and Latent Variables as a Function of Testing Wave and Groups With Reading Disability.

	Bilingual/RD							ELL/RD						
	Wave 1		Wave 2		Wave 3		Diff	Wave 1		Wave 2		Wave 3		Diff
Variable	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*
Achievement and language														
E-WD ID[a]	−0.89	0.78	−0.47	0.82	0.12	0.82	1.01	−0.61	0.74	−0.26	0.82	0.20	0.84	0.81
S-WD ID	−0.45	0.73	−0.10	0.65	0.31	1.14	0.76	−0.47	0.64	−0.20	0.54	0.01	0.70	0.48
E-Comp[a]	−0.90	0.90	−0.18	1.02	0.21	0.78	1.11	−0.62	0.88	−0.03	0.94	0.46	0.72	1.08
S-Comp	−0.47	0.59	−0.14	0.89	0.33	1.19	0.80	−0.43	0.66	−0.08	0.91	0.05	0.93	0.48
E-Vocabulary[a]	−0.09	1.01	0.21	1.01	1.04	0.98	1.13	−0.51	0.86	0.25	1.05	0.81	1.03	1.32
S-Vocabulary	0.32	1.05	0.38	1.08	0.60	1.12	0.28	−0.35	0.89	0.02	1.01	0.20	0.91	0.55
E-Oral Lang	−0.36	0.70	0.04	0.65	0.44	0.60	0.80	−0.26	0.58	0.17	0.61	0.50	0.56	0.76
S-Oral Lang	−0.02	0.60	0.22	0.68	0.41	0.72	0.43	−0.14	0.57	−0.02	0.6	0.16	0.61	0.30
Cognitive measures														
E-STM	−0.18	0.45	−0.09	0.34	0.15	0.34	0.33	−0.12	0.36	0.02	0.31	0.18	0.31	0.30
S-STM	−0.13	0.41	0.05	0.38	0.14	0.39	0.27	−0.14	0.35	0.01	0.31	0.05	0.30	0.19
E-WM	−0.10	0.30	−0.10	0.22	0.10	0.31	0.20	−0.12	0.31	−0.04	0.27	0.08	0.30	0.20
S-WM	−0.05	0.25	0.07	0.31	0.19	0.38	0.24	−0.12	0.20	0.01	0.25	0.12	0.29	0.24
Vis-WM	−0.09	0.35	0.18	0.32	0.42	0.54	0.51	−0.03	0.39	0.18	0.45	0.44	0.57	0.47
E-Phon.	−0.40	0.52	−0.13	0.49	0.15	0.55	0.55	−0.37	0.51	−0.15	0.45	0.03	0.54	0.40
S-Phon.	−0.22	0.43	−0.08	0.45	0.11	0.46	0.33	−0.33	0.41	−0.15	0.4	0.04	0.46	0.37
E-Naming Speed	−0.26	0.90	−0.13	0.60	0.07	0.67	0.33	−0.08	0.58	0.11	0.52	0.24	0.53	0.32
S-Naming Speed	0.02	0.41	−0.05	0.37	−0.01	0.30	−0.30	0.13	0.36	0.02	0.35	−0.04	0.27	−0.17
E-Inhibition	−0.10	0.45	−0.06	0.39	0.14	0.40	0.24	−0.08	0.43	0.13	0.41	0.22	0.51	0.30
S-Inhibition	−0.04	0.37	−0.07	0.38	0.07	0.32	0.11	−0.08	0.38	0.10	0.4	0.20	0.44	0.28

Note. All scores are in z-score units. Comp = Passage Comprehension subtest from *Woodcock-Muñoz Language Survey–Revised*; Diff = Difference Score, Wave 3 latent score minus Wave 1 latent score; E = English; NRD = no reading disability; Phon. = phonological processing; RD = reading disability; S = Spanish; STM = short-term memory; Vis-WM = visual-spatial sketchpad; Vocabulary = *Peabody Picture Vocabulary Test* (English) or the *Test de Vocabulario en Imagenes Peabody* (Spanish); WM = working memory executive component; Word ID = letter word identification.
[a]Classification measure.

Table A2. Mean z Scores for Manifest and Latent Variables as a Function of Testing Wave and Groups With No Reading Disability.

	Bilingual/NRD							ELL/NRD						
	Wave 1		Wave 2		Wave 3		Diff	Wave 1		Wave 2		Wave 3		Diff
Variable	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*
Achievement and language														
E-WD ID[a]	0.34	0.96	0.79	0.89	1.35	0.83	1.01	0.19	0.84	0.64	0.65	1.01	0.63	0.82
S-WD ID	0.31	1.10	0.64	1.07	1.04	1.15	0.73	−0.07	0.9	0.28	0.82	0.62	0.94	0.69
E-Comp[a]	0.36	0.89	0.86	0.69	1.24	0.62	0.88	0.17	0.83	0.68	0.61	1.01	0.65	0.84
S-Comp	0.28	1.11	0.69	1.16	1.13	1.21	0.85	−0.03	0.94	0.39	0.99	0.69	1.03	0.72
E-Vocabulary[a]	0.37	0.96	0.89	0.96	1.54	0.94	1.17	−0.4	0.86	0.49	0.93	1.15	0.99	1.55
S-Vocabulary	0.20	1.02	0.37	0.86	0.75	0.99	0.55	−0.38	0.81	0.11	0.74	0.44	0.76	0.82
E-Oral lang.	0.22	0.70	0.62	0.64	1.07	0.55	0.85	−0.07	0.64	0.45	0.56	0.75	0.58	0.82
S-Oral lang.	0.09	0.58	0.30	0.61	0.49	0.58	0.40	−0.09	0.58	0.19	0.56	0.30	0.62	0.39
Cognitive measures														
E-STM	0.07	0.36	0.25	0.33	0.38	0.33	0.31	0.03	0.36	0.16	0.33	0.32	0.35	0.29
S-STM	0.09	0.38	0.18	0.34	0.34	0.33	0.25	−0.02	0.31	0.13	0.32	0.24	0.31	0.26
E-WM	0.06	0.38	0.22	0.38	0.4	0.49	0.34	0.01	0.36	0.1	0.41	0.24	0.39	0.24
S-WM	0.05	0.27	0.17	0.32	0.36	0.39	0.31	0.01	0.27	0.1	0.32	0.24	0.31	0.24
Vis-WM	0.04	0.34	0.20	0.43	0.52	0.53	0.48	−0.02	0.3	0.23	0.43	0.55	0.53	0.57
E-Phon.	0.21	0.49	0.39	0.51	0.56	0.54	0.35	0.03	0.5	0.14	0.49	0.41	0.56	0.38
S-Phon.	0.16	0.53	0.32	0.51	0.59	0.59	0.43	0.01	0.52	0.1	0.47	0.41	0.58	0.40
E-Naming Speed	0.05	0.48	0.13	0.38	0.34	0.32	0.29	0.09	0.45	0.17	0.28	0.31	0.32	0.22
S-Naming Speed	−0.05	0.36	−0.14	0.32	−0.11	0.27	−0.06	−0.01	0.33	−0.05	0.27	−0.10	0.24	−0.09
E-Inhibition	0.03	0.39	0.13	0.39	0.30	0.42	0.27	0.06	0.38	0.21	0.46	0.33	0.41	0.27
S-Inhibition	0.01	0.37	0.10	0.39	0.20	0.34	0.19	0.05	0.36	0.14	0.41	0.25	0.33	0.20

Note. All scores are in z-score units. Comp = Passage Comprehension subtest from *Woodcock-Muñoz Language Survey–Revised*; Diff = Difference Score, Wave 3 latent score minus Wave 1 latent score; E = English; NRD = no reading disability; Phon. = phonological processing; RD = reading disability; S = Spanish; STM = short-term memory; Vis-WM = visual-spatial sketchpad; Vocabulary = *Peabody Picture Vocabulary Test* (English) or the *Test de Vocabulario en Imagenes Peabody* (Spanish); WM = working memory executive component; Word ID = Letter Word identification.
[a]Classification measure.

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Notes

1. Because the individual components of WM were critical to our analysis, we determined if a three-factor model that included the phonological loop (forward digit span, word span, phonological span, backward digit span), visual-spatial sketchpad (mapping, matrix), and the executive system (conceptual span, listening sentence span, updating, rhyming) fit the data within each language system. For the English presentation, the factor model provided an excellent fit to the data: CFI = 1.0; RMSEA = .04; NNFI = 1.02. For Spanish measures, the fit was also excellent: CFI = .99; RMSEA = .02; NNFI = .98.
2. A statistical test of convergence was conducted to determine whether the parameters (the intercepts, slopes, and error terms) were equal for each of the latent and manifest variables in the three cohort groups. Except for English inhibition, the configural model showed convergence (invariance) for all the cognitive, language, and reading measures (i.e., all CFIs > .95). Overall, the findings indicated that the intercept values for overlapping ages were statistically comparable.

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