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The role of verbal working memory in second language reading fluency and comprehension: A comparison of English and Korean

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Abstract

This study examined the respective contribution of verbal working memory, which was operationalized as immediate digit and sentence recall, to bilingual children's reading fluency and comprehension in the first language (L1) and second language (L2). Fifty children from two international sites took part in this study: One group was English-Korean bilinguals in the U.S., while the other was Korean-English bilinguals in Korea. The manifestation of the prediction model varied across the learning contexts or learner groups. L1 forward and backward digit spans accounted for the significant variances in L2 reading fluency and comprehension for the English-speaking children in the U.S., whereas L1 forward digit span was more predictive of L2 reading fluency and comprehension than backward digit span and sentence recall for the Korean-speaking counterparts in Korea. The results were interpreted with respect to the orthographic depth, linguistic differences, and cognitive demands. Implications and future directions are discussed.

Keywords: Reading fluency and comprehension; English-Korean bilinguals; Korean-English bilinguals; verbal memory

Introduction

Since Baddeley and Hitch's publication (1974) on the construct of working memory, researchers have investigated not only the nature, structure, and function of working memory but also its relation to children's language and reading acquisition (Daneman & Carpenter, 1980; Gathercole & Baddeley, 1993; Windfuhr & Snowling, 2001). Working memory refers to the transitory storage capacity and operations that manipulate verbal or written input while processing incoming information and retrieving relevant phonological information from the long-term lexicon (Miller & Kupfermann, 2009). It works as a processing

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source for the active maintenance of task-relevant information while simultaneously processing the same or other information activated along with task operations (Swanson, Zheng, & Jerman, 2009). Under the working memory model (Baddeley, 1986), verbal short-term memory or the phonological loop captures a subset of working memory performance. This subsystem is usually measured using immediate serial recall tasks in which the examinee is verbally presented with the sequence of isolated digits or words (Gupta, 1996).

Learning relies on an individual's ability to conceptualize and categorize new information and to make associations with other information housed in mental storage. Given the importance of mental storage, working memory has received abundant attention over time. Limited auditory memory span is one of the sources of deficiencies in language processing because a reduced memory span can inhibit the efficiency of working memory, which is necessary for processing and comprehending extended verbal narrations (Gathercole & Baddeley, 1993; Miller & Kupfermann, 2009).

There have been conflicting views on the definitions of working memory and short-term memory. Some researchers (Colom, Flores-Mendoza, Quiroga, & Privado, 2005; Gathercole, 1998; Unsworth & Engle, 2007) have differentiated working memory from short-term memory, while others (McDougall, Hulme, Elllis, & Monk, 1994) have used the two terms interchangeably. The former's rationale is based on the claim that working memory relies on the central executive system with a heavy demand of information manipulation. In other words, short-term memory works to retrieve a sequence of items in the order in which information is stored without manipulations, while working memory requires recalling information that is transformed from its initial encoding in order to perform task-relevant operations through manipulations (Swanson, Zheng, & Jerman, 2009). The latter upholds a claim that working memory and short-term memory share some commonalities on the learner's part with regard to the speech-based phonological input memory bank and extra-transformational processes. Regardless of the position on the relationship between working memory and short-term memory, working memory and short-term memory are forms of transient memory. Since this study was not designed to test memory models, verbal memory was operationalized as transitory immediate digit and sentence recall or memory in this paper. The purpose of this study was to investigate the manifestation of cognitive demands necessary for first language (L1) and second language (L2) reading.

Relationships Between Phonological and Verbal Memory and Reading

Given the way that phonological coding contributes to the retention of information in working memory and vice versa, studies have demonstrated a significant association between verbal memory span and word reading (Jeffries & Everatt, 2004; Johnston, Rugg, & Scott, 1987; Jorm, Share, Maclean, & Matthews, 1984). Deficits in verbal working memory and slow or imprecise word recognition impede higher-order processes, such as semantic retrieval and syntactic judgment, due to a lack of residual cognitive space. As a result, it leads to significantly reduced reading comprehension (Katz, Shankweiler, & Liberman, 1981; Stanovich, Siegel, & Gottardo, 1997). Because neighborhood candidates (e.g., phonology, spelling patterns, syntax, and semantic properties) are activated upon the stimulus of the text in the face of interference (Swanson, Zheng, & Jerman, 2009), effective activation and inhibition processes through the maintenance of pertinent memory traces are crucial while reading. Therefore, the efficiency of the informational filtering system through memory traces facilitates reading comprehension.

Due to its phonological processing and the maintenance of task-relevant information in an active state, verbal memory is robustly related to the performance of complex cognitive tasks, such as vocabulary acquisition and reading (Baddeley, 1986). Research has demonstrated that verbal short-term memory abilities and reading acquisition have a shared set of processes and utilize a common cognitive system (Adams & Gathercole, 1996; Gupta, 1996; Gupta & MacWhinney, Feldman, & Sacco, 2003; Henry & MacLean, 2003). A reliable relationship has been observed between digit span recall and word knowledge even when other variables, such as age and IQ scores, were controlled for (Gernsbacher, 1990; Gupta, 1996).

Gupta (1996) has attempted to explain the relation between immediate serial recall and word learning using a computational model in which a general sequencing mechanism provides immediate memory for the sequence of word forms. The model consists of three vital levels, including a phoneme layer, a phonological-chunk layer, and a semantic/context layer. The phoneme layer relates to output phonology at which phonemes are represented. The phonological-chunk layer entails the representations for word forms which are shared by input and output phonology. The last level, the semantic/context layer, represents semantic and contextual information about word forms (see Gupta, 1996, for details). According to Gupta's (1996) model which takes a new processing-oriented approach to examining word learning, the significant relationship between immediate serial recall and word learning lies in the common dependence of these two capabilities on core phonological and semantic processing mechanisms.

As a whole, verbal memory is indispensable with regard to reading in that textual inputs go through multiple processes, including encoding and retrieval of phonological, orthographic, and semantic referents stored in the mental lexicon (Gupta, 1996; Swanson, Saez, & Gerber, 2006). Through these processes, activated information about words, phrases or sentences should be sustained for a short period of time in order for the contents to be integrated into a context.

Daneman and Carpenter (1980) developed a reading-span test (RST) to investigate the contribution of working memory to reading comprehension. In the RST, participants read a few sentences aloud and were asked to remember the last word of each sentence. Due to the limited capacity of working memory, the mental resources to read a sentence and store the last word of each sentence were limited. Since participants needed to allocate mental resources efficiently during the task, the RST measured storing and processing capabilities concurrently upon reading. There was a significant correlation found between the RST score and reading comprehension performance (Daneman & Carpenter, 1980). A meta-analysis of studies using working memory-span tasks conducted by Daneman and Merikle (1996) also showed that working-memory-span capacity was correlated significantly with reading skills.

There are individual differences in working memory capacity and these differences are related, in part, to language comprehension (Daneman & Carpenter, 1983; Just & Carpenter, 1992). Daneman and Carpenter (1983) have suggested that the semantic processing of sentence comprehension is attributable to individual differences in memory capacity. Students who show efficient working memory retrieval (i.e., higher scores on the RST) are more likely to make use of fewer resources for the semantic processing of sentences, and, as a result, have sufficient resources to retain the words. In contrast, participants who show inefficient working memory (i.e., lower scores on the RST) have difficulty retaining target words due to the insufficient working memory capacity during reading. Similarly, from a capacity-oriented perspective, skilled readers make more text-based inferences because the multiple sources of processing, such as reading a sentence and storing the last word of each sentence at the same time, are available in working memory. Hence, high functioning students with greater working memory capacity are able to sustain more information necessary to complete the given task, such as reading, because they successfully utilize the efficient activation of semantic and syntactic information (Budd, Whitney, & Turley, 1995).

L1 and L2 Interdependence and the Korean Language

A myriad of studies have demonstrated cross-language links in the acquisition of language and reading skills, and been explained by the cross-linguistic interdependence hypothesis (Cummins, 1994). Phonological processing skills, for example, can transfer from one language to another (Gottardo, Yan, Siegel, & Wade-Woolley, 2001; Pae, Sevcik, & Morris, 2010). If one has robust L1[1] oral skills and reading proficiency, the likelihood for the child to gain success in L2 oral performance and reading is greater than those who lack those skills. Within the Roman alphabetic languages, children are able to make use of commonalities between L1 and L2, when they learn L2. Although universality exists in the acquisition of languages, language-specific variations are observed, because learning to read accommodates how a writing system maps phonological properties in the language under consideration (Pae, 2011; Perfetti & Liu, 2005). Therefore, it is possible that working memory and L1 ability may influence the learning of some second languages more than others, particularly if those languages use different forms of script or orthography.

The ability to control attention for the active maintenance of given information and the inhibition of irrelevant information is viewed as a domain-general construct (Kane et al., 2004; Payne, Kalibatseva, & Jungers, 2009). With robust evidence that verbal memory skills contribute to L1 reading comprehension (Daneman & Carpenter, 1980, 1983; Kane et al., 2004; Swanson & Berninger, 1995), the significant role of working memory has been expanded to the prediction of L2 language processing and reading comprehension. For instance, independent contributions of working memory for Hebrew-speaking high-school students were found in their learning English as L2 (Abu-Rabia, Share, & Mansour, 2003). A study of Japanese-speaking students evidenced a significant correlation in working memory between L1 and L2, as well as a mediator effect of L2 working memory on the relationship between L1 working memory and L2 syntactic comprehension (Miyake & Friedman, 1998). Significant relationships among variables of working memory, L1 reading comprehension, and L2 reading comprehension were also found in English-speaking college students' Spanish comprehension (Payne, Kalibatseva, & Jungers, 2009). A salient contribution of verbal working memory, measured using memory span and tongue twister, to text comprehension by Chinese children has also been reported (Leong, Tse, Loh, & Hau, 2008). The significant role of phonological memory has been expanded to L2 speech production for English-speaking adults who were learning Spanish as L2. O'Brien, Segalowitz, Collentine, and Freed (2006) found that phonological memory (serial nonword recognition) explained significant amounts of the variance in L2 narrative oral skills for both less proficient and more proficient adults, after controlling for speech output.

In cross-language research, a study of English and Korean offers an excellent opportunity to examine between-language interdependence because the two languages share the alphabetic principle (Pae, 2011; Ziegler & Goswami, 2005), but exhibit profound differences in their visual lexical form (linearity vs. block layout) as well as orthographic, phonological, and linguistic features. Korean is noticeably different from other languages in its origin; the

[1] Since L1 is to be processed automatically, the automaticity can be a way to determine the child's L1. In this study, a dominant language and L1 are operationalized as the language in which a child knows *instantly, intuitively, and effortlessly*, when he/she processes an utterance in a language, regardless of the first language to which the child was exposed. Hence, L1 was used throughout the paper for the sake of consistency with previous studies in order to refer to a dominant language.

Korean writing system was invented and promulgated by King Sejong in 1443, rather than being evolved over time. The key differences between English and Korean include lexicality and orthographic depth, writing systems, phonological differences, syntactic word order in sentences, and subject and/or object omissions in sentences.

English is considered to be a deep orthography (Katz & Frost, 1992), while Korean is a shallow orthography in which any words, even if unfamiliar words or nonwords, can be sounded out quickly and accurately. The Korean writing system, an alphabetic syllabary (Pae, 2011; Taylor, 1980, 1997), is unlike those of most other Roman alphabetic languages. The graphemes are not written one after another in a horizontal line, but form a square-like syllable block consisting essentially of a phonetic syllable (e.g., 한글 rather than ㅎㅏㄴㄱㅡㄹ). The number of Korean syllables currently in use in Korea is 2,457 (see Pae, 2011 for details), which is larger than Chinese which contains about 400 syllables or 1,300 syllables with tones (Taylor, 1997) and Japanese that includes fewer than 113 syllables (Taylor, 1997). However, the number of syllables is much smaller than that of English which includes about 8,000 syllables (Katz & Frost, 1992). Korean phonemes do not include the labio-dentals, interdentals, sibilants, or retroflexes that are found in English.

Korean falls into the Ural-Altaic family of language, with an agglutinative structure of grammar (i.e., nouns and verbs are formed by attaching derivational and/or inflectional prefixes and suffixes to the root). The basic syntactic structure of Korean, like Japanese, is a predicate-final structure with the basic word order of Subject-Object-Predicate (verb or adjective). In other words, Korean is a verb/predicate-final language (i.e., a language in which the verb or predicate always comes at the end of the sentence; Sohn, 1999). The Korean language is a context-rich language in that most of the sentences do not carry subjects, and, often times, objects are also omitted. The listener is forced to rely on the context in which the utterance takes place in order to comprehend the true meaning of the sentence. For example, "I love you" in English can be said "love" in Korean. With the omissions of the subject and the object, both the speaker and the listener are able to decipher the meaning of the utterance without problems in Korean by relying on the context in which communication occurs.

The Present Study

Despite the comparatively wide knowledge base on literacy acquisition in linearly arranged alphabetic languages, little is known about literacy development in writing systems with non-linear symbol arrangements. Korean is an outstanding example of alphasyllabic languages, as briefly noted earlier, because it entails the alphabetic principle (i.e., a grapheme maps onto a phoneme and strings of graphemes form a syllable) as well as a distinct visual syllabic structure with an adhesive rule of a consonant to a vowel. No consonant strings are allowed, except five doublets (ㄲ ㄸ ㅃ ㅆ ㅉ) and legal consonant-consonant forms at the bottom of the top-down syllable (see Pae, 2011, for more details).

Given that reading is a high-order cognitive function, the aim of this study was to investigate the independent contributions of three different types of verbal working memory to L2 reading fluency and comprehension via a comparison of English and Korean. Two research questions were posed as follows:

1. What is the individual contribution of phonological working memory, verbal digit working memory, and sentence verbal working memory to L1 and L2 reading for English-speaking bilinguals in the U.S. who learn Korean as L2[2]?

[2] Again, for the sake of consistency, L1 and L2 were used in this study, although the U.S. children might have exposed to Korean first, regardless the dominance of language skills in English and Korean. The U.S. participants'

2. What is the individual contribution of phonological working memory, verbal digit working memory, and verbal sentence working memory to L1 and L2 reading for Korean-speaking bilinguals in Korea who learn English as L2?

On the basis of the findings of previous research, it was assumed that phonological working memory, measured using forward digit spans, has more of a working memory load than the sentence task for children, while verbal digit working memory has an extra transformational processing element and has the highest demand for working memory processes. Verbal sentence working memory includes a rich set of contextual and semantic information, allowing for long-term memory traces that should free up working memory to some extent. This task may have the least load on working memory process. Therefore, it was hypothesized that verbal digit working memory was more predictive for comprehension than phonological working memory and sentence recall skills.

Although the literature indicates a significant relationship between L1 verbal memory and L2 reading comprehension in Roman alphabetic languages, there has been little exploration of the role of verbal working memory in accounting for reading comprehension in an alphasyllabic language. We hypothesized that verbal memory capacity in L1 would be predictive of reading achievement in both L1 and L2, but the extent to which verbal memory played a role in English and Korean performance would be different when learning the language as L2. Because Korean has a consistent grapheme-phoneme correspondence, Korean involves direct lexical access in text processing with a little phonological mediation[3]. Given the grapheme-phoneme consistency in Korean, it was also hypothesized that the amount of variance explained by verbal memory would be smaller in Korean than that in English when learning the language as L2.

We also examined whether differences exist between English-speaking bilinguals and their Korean-speaking counterparts in terms of the strength of relationship between L1 and L2. This analysis would lead to a better understanding of L2 acquisition in learning contexts: one in an English-as-a-second-language (ESL)[4] context by English-Korean bilinguals and the other in an English-as-a-foreign-language (EFL) context by Korean-English bilinguals. If the language system had an influence on reading performance, verbal memory would play a role in a different way across sites where the L1 is different from each other. We expected a different pattern of relationship between verbal working memory and reading (i.e., different amount of the variance explained in the prediction model) across the two sites.

Methods

Participants

Fifty first- and second-grade children took part in this study. The participants consisted of two groups. The first group comprised 29 Korean immigrant children residing in the U.S. who

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home language was predominantly Korean, although the children mostly communicate in English at school and at home in which Korean was spoken by the participant's parent.

[3] The dual-route hypothesis, including the lexical route (a.k.a., addressed, word-detector, or lexical look-up route) and the sublexical route (a.k.a., nonlexical, assembly, rule-based, or phonologically mediated procedure), offers an explanation of mapping print into sound. Since the word processing route was beyond the scope of this study, the two routes were not considered in this study.

[4] Although it can be questionable as to whether the Korean-immigrant children in the U.S. were actually learning Korean as an L2-equivalent language, the questionnaire by participant's parent and a brief interview with the child pointed to language automaticity established in English. See Results for further information on the language dominance.

were learning Korean as L2 (English-Korean bilinguals) within a Korean educational program (i.e., a Saturday school) in a metropolitan area in the southeastern United States. The second group was composed of 21 Korean natives who lived in Korea and learned English as L2 (Korean-English bilinguals) in the formal education setting in Busan, South Korea. In order to match the socioeconomic status across the sites, the participants in South Korea were restricted to students who were attending a private elementary school. Parental informed consent and child assent were obtained for all the participants.

The English-Korean learners' mean age was 91.82 months (SD = 8.62; 15 males, 14 females). The Korean-English counterparts' mean age was 87.66 months (SD = 5.92; 13 males, 8 females).

The parent questionnaire and the child oral report indicated that all the participants were not exposed to other languages beyond the two languages under consideration. It should be noted that the English-Korean bilingual children in the U.S. might have been exposed to Korean first because their parents spoke Korean at home. The questionnaires completed by the parent and brief interviews with the children indicated that the parent typically spoke to the child in Korean, and the child responded to his/her parent in English. Hence, the strength of their language skills was shown in English, and their oral production in Korean was laborious, which was a typical indication of L2. Because of the wide range of variability in both home-language use and language dominance for the English-Korean speaking bilinguals, the U.S. participants' dominant language was validated using object picture naming latency in L1 and L2. This validation procedure was derived from the premise that object naming in L1 is typically faster than L2, due to the additional processing demand to resolve a competition from L1 candidates (Kroll & Stewart, 1994). The results showed that the participants took significantly longer naming objects in L2 than L1 [U.S. participants: $t(1,28) = 7.70$, $p < .00$], validating the participants' and parents' self-reports. Since the Korean native students spoke Korean as their L1, the validation procedure was not necessary.

Procedure

A test battery, which included measures of forward and backward digit recall, sentence recall, and reading skills, was individually administered at the Korean schools or the participant's home by a bilingual examiner. Before the test administration, a brief interview with the child was performed, in addition to child assent.

Measures

Based on the protocols of English measures which were U.S. norm-referenced, the Korean measures were experimentally designed to achieve comparability with the English version. Word frequency, face validity, inter-item consistency, and test-retest reliability were taken into account to overcome potential limitations and to maximize the cross-cultural comparability. For the experimental Korean measures, internal consistency and test-retest reliability coefficients ranged from .79 to .91.

Predictor Measures

Phonological Working Memory. The Forward Digit Span subtest of the Wechsler Intelligence Scale for Children-Third Edition (WISC-III; Wechsler, 1991) was used as a measure of phonological working memory. The forward digit span task required an immediate recall of auditory number strings forwards at a rate of one digit per second and asked the child to simply repeat the list of digits as heard. This task involves a phonological memory reservoir that stores in-coming information passively for a few seconds, and then produces articulatory output under constraints.

Verbal Digit Working Memory. The Backward Digit Span subtest of the WISC-III (Wechsler, 1991) was used as a measure of verbal digit memory. This test asked the child to say the list of numbers in a reversed order for an instant recall. Since it was designed to measure the participant's ability to store and manipulate digits that were in temporary short-term memory, this task entailed an extra-transformational processing element. It required the child not only to recite the presented information, but also to make some transformation. The additional processing on top of memory makes this task quite powerful and consistent predictor of a wide array of high order processes related to fluid intelligence, such as reading comprehension.

For the forward and backward digit span tests, a set of two lists with the same length was provided, and if at least one of the two lists was correctly produced, the subsequent list was increased by one digit until the child reached the ceiling. The internal consistency values and test-retest reliability coefficients for age groups of 6 to 9 were high, ranging from .89 to .94.

The same protocol was used for the Korean measure, but the digits were presented in Korean by the examiner and the participants responded in Korean as well. Since the articulation of the number in a language involves its phonological coding, using the same stimuli in the two languages maintains a unitary construct.

Verbal Sentence Short-Term Memory. The Sentence Repetition subtest of *A Developmental Neuropsychological Assessment* (Korkman, Kirk, & Kemp, 1998) assessed the ability to recall sentences of increasing complexity and length. The examinee was asked to repeat verbatim the sentence presented by the examiner. The generalizability coefficients for children of 6 to 9 years of age ranged from .72 to .85. The stability coefficient was .91 for that age group. The Korean measure of sentence repetition was constructed on the basis of the English version, by attending to the word and sentence lengths and the semantic complexities of the given sentences. The internal consistency coefficient was .81 for the Korean sentence repetition test.

Outcome Measures

Reading Fluency. The Fluency subtest of the Gray Oral Reading Test-4 (GORT-4; Wiederholt & Bryant, 2001) was employed as a reading fluency assessment tool. The GORT-4 is composed of 4 subtests, including reading rate, accuracy, fluency, and comprehension; the fluency score is a composite score of rate and accuracy scores. The GORT-4 was designed to determine the particular reading strengths and weaknesses that individual students possess and to serve as a measurement device in assessing reading ability (Wiederholt & Bryant, 2001).

Reading Comprehension. The Comprehension subtest of the Gray Oral Reading Test-4[5] (GORT-4; Wiederholt & Bryant, 2001) was employed as a reading comprehension assessment tool. The GORT-4 evidences a high degree of reliability, which was consistently high across all three types of reliability: content sampling ranged from .91 to .97; test-retest, .85 - .95; and scorer differences, .94 - .99. For the Korean version of the reading fluency and comprehension measures, Form B stories of the GORT-4 were translated into Korean so that the participants could receive an equivalent fluency and comprehension measures in the two languages.

[5] There have been concerns about content validity and concurrent validity of the GORT-4 (Keenan & Betjemann, 2006). However, Keenan & Betjemann (2006) administered the GORT passages to college students to examine the extent to which GORT questions were passage-independent items. Since our participants' ages fell in the range of the GORT-4' normative sample which was 6-18 years of age, we followed the GORT manual.

Results

Descriptive Statistics and Correlations

A descriptive analysis of all data was initially conducted, including an examination of variable means and standard deviations, outlier checks, and the distribution of scores. Since the focal point centered on reading fluency and comprehension in relation to verbal memory, word and nonword identification skills were not included as variables in this study. The distribution of the raw scores on the reading tests was slightly positively and negatively skewed according to the measures, but no outstanding differences were found for the planned inferential statistical analyses. Due to cross-cultural measurement issues given that no measures utilized were normed in Korea, raw scores were used for analyses. As expected, the participants consistently demonstrated higher performance in their L1 than L2, which was a typical pattern found in previous research (Pae, Sevcik, & Morris, 2004, 2010). The two groups did not differ in age as assessed by a *t*-test corrected for unequal variances, $t = 1.91$, $p > .05$. Although the U.S. children slightly outperformed the Korean counterparts, the children's performance on the measures was not significantly different for the U.S. and Korean groups, except for L1 sentence repetition and L1 backward digit span ($F = 8.17$, $p < .01$; $F = 9.90$, $p < .01$, respectively). Table 1 shows the means and standard deviations for L1 and L2 measures. The reading measures, including fluency and comprehension, did not differ between the two groups.

Table1. *Descriptive Statistics*

	English-Korean Bilinguals			*Korean-English Bilinguals*		
	Mean	*SD*	*Range*	*Mean*	*SD*	*Range*
L1 Forward Digit Span	7.69	1.83	5-11	7.19	1.57	5-10
L2 Forward Digit Span	5.90	1.49	4-9	6.05	1.32	4-8
L1 Backward Digit Span	5.55	1.84	2-9	4.67	1.15	3-7
L2 Backward Digit Span	3.83	1.23	2-6	3.71	1.27	2-6
L1 Sentence Repetition	16.72	3.99	9-26	13.57	3.64	8-20
L2 Sentence Repetition	10.10	4.04	3-19	8.81	2.44	6-14
L1 Reading Fluency	40.69	17.39	1-71	40	15.93	16-84
L2 Reading Fluency	8.10	7.52	0-25	11.90	7.65	0-35
L1 Reading Comprehension	20.28	11.09	0-42	16.10	8.65	5-40
L2 Reading Comprehension	6.21	3.89	0-13	6.81	4.02	0-18

Since each participant was tested on L1 and L2 skills across the two sites, and provided scores for each permutation of the variables, ANOVA was performed with two foci. The first focus was placed on the difference between the learner groups (i.e., ESL U.S. vs. EFL Korea) to examine main effects and interactions with site (U.S. vs. Korea) as the between-subject factor and language (L1 vs. L2) as the within-subject factor. The results revealed a main effect of language ($F(1, 48) = 42.21$, $p = .000$, partial $\eta^2 = .32$), indicating that there are differences in the means of reading fluency skills between the two learner groups when ignoring other factors. There was an interaction effect, indicating that the children's performance was not the same at the two sites [$F(1,48) = 5.27$, $p = .026$, partial $\eta^2 = .10$]. Main effects for sentence repetition, forward digit span, and backward digit span were significant. There were interaction effects for forward and backward digit span [$F(1, 48) = 4.45$, $p = .04$, partial $\eta^2 = .09$; $F(1, 48) = 4.38$, $p = .04$, partial $\eta^2 = .08$, respectively], suggesting that the verbal memory skills in digit span were not uniform. The two-way interaction between the two sites for the sentence repetition task did not reach significance [$F(1, 48) = 3.52$, $p = .07$, partial $\eta^2 = .07$].

For the reading measures, there were significant main effects for reading fluency and reading comprehension performance. A markedly significant interaction implied that this pattern of variance was different for the two participant groups.

The second focus was placed on the language command (i.e., L1 vs. L2). Since the language command was a within-subject variable, the main effect and interaction effect were not reported. The L1 backward digit span and L1 sentence repetition were significantly different across language commands ($F(1,48) = 9.90$, $p = .003$, $F(1,48) = 8.17$, $p = .006$, respectively).

Zero-order correlation coefficients among the variables were obtained. Table 2 reports the bivariate correlation coefficients in the lower-left triangle and the partial correlation coefficients controlling for age in the upper-right triangle for the English-speaking participants. The partial correlation coefficients were computed because verbal memory is age-sensitive. For the U.S. students, there were moderate to high significant correlations among the variables under consideration after controlling for age (*r* ranges: .41 - .85, $p < .05$). Interestingly, the sentence repetition performance showed the lowest correlations with the other variables.

For the Korean counterparts, the pattern of the significant correlations among the variables was different from that of the English-speaking participants (see Table 3). Korean (L1) sentence recall proficiency was significantly correlated with Korean (L1) and English (L2) backward digit span ($r = .52$ and .57, respectively) after controlling for age. Overall, the Korean natives' scores showed comparatively lower correlations among the variables under consideration than those of the U.S. children.

Table 2. *Correlations among the Variables below the Diagonal and Partial Correlations Controlling for Age above the Diagonal for the English-Speaking Children in the U.S.*

	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1. L1 Forward Digit Span	1	.85***	.51**	.43*	.62***	.38*	.65***	.47*	.28	.49**
2. L2 Forward Digit Span	.84***	1	.45*	.34	.48*	.49**	.59**	.43*	.23	.56**
3. L1 Backward Digit Span	.51**	.46*	1	.59**	.50**	.32	.64***	.56**	.62***	.54**
4. L2 Backward Digit Span	.44*	.36	.61**	1	.44*	.23	.45*	.41*	.51**	.44*
5. L1 Sentence Repetition	.61***	.47*	.45*	.41*	1	.54	.63***	.36	.36	.15
6. L2 Sentence Repetition	.35	.45*	.23	.17	.54**	1	.49**	.43*	.37	.36
7. L1 Reading Fluency	.65***	.59**	.64***	.46*	.62**	.44*	1	.71***	.70***	.64***
8. L2 Reading Fluency	.47*	.42*	.52**	.40*	.37	.42*	.70***	1	.70***	.79***
9. L1 Reading Comprehension	.25	.19	.48**	.42*	.36	.41*	.63***	.68***	1	.64***
10. L2 Reading Comprehension	.49**	.57**	.55**	.45*	.14	.32	.64***	.78***	.58**	1

*$p < .05$; ** $p < .01$; *** $p < .001$

Table 3. *Correlations among the Variables below the Diagonal and Partial Correlations Controlling for Age above the Diagonal for the Korean-Speaking Children in Korea*

	1	2	3	4	5	6	7	8	9	10
1. L1 Forward Digit Span	1	.48*	.31	.54*	.37	.58**	-.03	.58**	-.06	.50*
2. L2 Forward Digit Span	.57**	1	.48*	.70**	.40	.36	-.02	.30	.18	.36
3. L1 Backward Digit Span	.39	.57**	1	.63**	.52*	.66**	-.13	.23	-.27	.07
4. L2 Backward Digit Span	.61**	.75***	.68**	1	.57**	.50*	.16	.44	.12	.42
5. L1 Sentence Repetition	.47*	.56**	.60*	.64**	1	.54*	.06	.22	-.15	.09
6. L2 Sentence Repetition	.64**	.50*	.70***	.58**	.63**	1	-.04	.59**	-.17	.39
7. L1 Reading Fluency	.08	.15	-.02	.25	.18	.08	1	.16	.84***	.29
8. L2 Reading Fluency	.64**	.45*	.33	.52*	.36	.65**	.25	1	.03	.87***
9. L1 Reading Comprehension	-.03	.19	-.23	.14	-.10	-.13	.83***	.05	1	.29
10. L2 Reading Comprehension	.51*	.36	.10	.43	.13	.40	.31	.84***	.30	1

*$p < .05$; ** $p < .01$; *** $p < .001$

Hierarchical Regression Analyses for Reading Fluency and Comprehension

In order to explore the respective contribution of the phonological and verbal memory in L1 and L2 reading skills, a series of hierarchically nested regressions were performed separately for each learner group. After controlling for age, forward digit span capacity was entered first, backward digit span second, and then sentence repetition was entered last into a model as predictor variables. Reading fluency and comprehension skills served as dependent variables. The within-language analyses of L1-L1 and L2-L2 as well as the between-language analysis of L1-L2 were performed. The results of hierarchical regression analyses for the English-speaking children are shown in Table 4.

The English forward digit span accounted for 41% of the unique variance in English reading fluency (F change (1,26) = 19.14, p = .000), and the English backward digit span explained an additional 13% of the variance in English reading fluency (F change (1,25) = 7.04, p = .014). The English backward digit span was predictive of 29% of the unique variance of English reading comprehension (F change (1,25) = 12.53, p = .002). The L2 Korean forward digit span was also a significant predictor of L2 Korean fluency and comprehension skills (17% and 31% of the unique variance, respectively). When it came to cross-language prediction, the English forward and backward digit span tasks explained the unique variances in both Korean reading fluency and reading comprehension. The English (L1) forward digit span task explained 23% and the English backward digit span measure accounted for 13% of the additional unique variance in Korean (L2) reading fluency (F change (1,26) = 7.54, p = .010; F change (1,25) = 5.35, p = .029, respectively). The English (L1) forward span task explained 23% of the unique variance and the backward digit span test accounted for an additional 11% of the unique variance in Korean (L2) reading comprehension (F change (1,26) = 8.26, p = .008; F change (1,25) = 4.31, p = .048, respectively).

Table 4. *Hierarchical Regression Models for English-Korean Bilinguals in the U.S.*

Dependent Variables	Predictors	R^2	ΔR^2	β	t
Within Language (English-English)					
L1 Fluency	Step 1. Age	.02	.02	ns	ns
	Step 2. L1 Forward Digits	.43***	.41***	.44	2.81*
	Step 3. L1 Backward Digits	.56***	.13*	.44	2.65*
	Step 4. L1 Sentences	.60***	.04	ns	ns
L1 Comprehension	Step 1. Age	.07	.07	.46	2.73*
	Step 2. L1 Forward Digits	.14	.07	ns	ns
	Step 3. L1 Backward Digits	.43**	.29**	.63	3.21**
	Step 4. L1 Sentences	.44**	.01	ns	ns
Within Language (Korean-Korean)					
L2 Fluency	Step 1. Age	.00	.00	ns	ns
	Step 2. L2 Forward Digits	.18	.18*	ns	ns
	Step 3. L2 Backward Digits	.26	.08	ns	ns
	Step 4. L2 Sentences	.32	.06	ns	ns
L2 Comprehension	Step 1. Age	.02	.02	ns	ns
	Step 2. L2 Forward Digits	.33**	.31**	.42	2.22*
	Step 3. L2 Backward Digits	.39**	.06	ns	ns
	Step 4. L2 Sentences	.40*	.01	ns	ns
Between Languages (English-Korean)					
L2 Fluency	Step 1. Age	.00	.00	ns	ns
	Step 2. L1 Forward Digits	.23*	.23*	.48	7.54*
	Step 3. L1 Backward Digits	.36*	.13*	.46	2.20*
	Step 4. L1 Sentences	.36*	.00	ns	ns
L2 Comprehension	Step 1. Age	.02	.02	ns	ns
	Step 2. L1 Forward Digits	.25*	.23**	.48	2.36*
	Step 3. L1 Backward Digits	.36**	.11*	.51	2.64*
	Step 4. L1 Sentences	.45**	.09	ns	ns

Note * $p < .05$; ** $p < .01$; *** $p < .001$
ns = not significant

As seen in the correlation matrix, a difference of the prediction was also found in the regression analysis for the Korean-speaking children from the English-speaking counterparts (see Table 5). As hypothesized, the predictive power of the phonological and verbal memory skills in reading fluency and comprehension diminished for the Korean-speaking children. In the Korean (L1) within-language relationship, no predictors accounted for the significant variance in Korean reading fluency and comprehension. The English (L2) sentence repetition task explained 15% of the unique variance in English reading fluency (*F* change (1,16) = 4.59, *p* = .048). The Korean (L1) forward digit span explained a unique variance of 28% in English (L2) reading fluency and an additional 24% of the variance in L2 reading comprehension.

Table 5. *Hierarchical Regression Models for Korean-English Bilinguals in Korea*

Dependent Variables	Predictors	R^2	ΔR^2	β	t
Within Language (Korean-Korean)					
L1 Fluency	Step 1. Age	.08	.08	ns	ns
	Step 2. L1 Forward Digits	.08	.00	ns	ns
	Step 3. L1 Backward Digits	.09	.01	ns	ns
	Step 4. L1 Sentences	.11	.02	ns	ns
L1 Comprehension	Step 1. Age	.01	.01	ns	ns
	Step 2. L1 Forward Digits	.01	.00	ns	ns
	Step 3. L1 Backward Digits	.08	.07	ns	ns
	Step 4. L1 Sentences	.08	.00	ns	Ns

Hierarchical Regression Models for Korean-English Bilinguals in Korea

Dependent Variables	Predictors	R^2	ΔR^2	β	t
Within Language (English-English)					
L2 Fluency	Step 1. Age	.15	.15		
	Step 2. L2 Forward Digits	.23	.08		
	Step 3. L2 Backward Digits	.32	.09		
	Step 4. L2 Sentences	.47*	.15*	.49	2.14*
L2 Comprehension	Step 1. Age	.02	.02		
	Step 2. L2 Forward Digits	.14	.12		
	Step 3. L2 Backward Digits	.19	.05		
	Step 4. L2 Sentences	.24	.04		
Between Languages (Korean-English)					
L2 Fluency	Step 1. Age	.15	.15		
	Step 2. L1 Forward Digits	.43**	.28**	.56	2.55*
	Step 3. L1 Backward Digits	.44*	.01		
	Step 4. L1 Sentences	.44*	.00		
L2 Comprehension	Step 1. Age	.02	.02		
	Step 2. L1 Forward Digits	.26	.24*	.58	2.34*
	Step 3. L1 Backward Digits	.27	.01		
	Step 4. L1 Sentences	.28	.01		

Discussion

The aim of this study was to investigate the extent to which phonological and verbal memory capacity, as indicated by forward and backward digit spans and sentence immediate recall tasks, affected reading outcomes in English and Korean by English-Korean and Korean-English bilinguals. The general pattern of L1 and L2 performance by the participants in the two international sites was consistent with the findings of previous research, indicating that the students demonstrated a greater strength in L1 than L2 (Pae, Sevcik, & Morris, 2004, 2010). The pattern of the bilinguals' performance on the given measures was different across the two sites. The difference in reading outcomes might result from the L2 learning context; one with an ESL context and the other with an EFL context.

Obviously, the EFL students in Korea, in which the Korean language is ubiquitously spoken, have limited L2 exposure, input, and use, compared to their ESL counterparts in the U.S. whose dual languages are spoken on a daily basis. The English-speaking children in the U.S. appeared to perform better in phonological and verbal memory tasks. Since phonological and verbal memory is closely linked to the phonological representations of the language, the richer phonological component of English (due to the number of legal sequences in speech sounds) than Korean might have influenced the English-speaking children's verbal memory performance. As stated earlier, the number of syllables in English and Korean is drastically different (2,000 vs. 8,000). This finding suggests that the availability of a wide range of phonological information may facilitate the maintenance and manipulation of input information and eventually help the production of the stored phonological information. However, further research is warranted for the explanation of the role of phonological and verbal memory in reading across different languages.

The partial correlations, controlling for age, showed significant correlations between L1 and L2. This result is consistent with the notion of cross-language interdependence (Cummins, 1994). There were significant correlations between phonological memory and verbal working memory and between these skills in L1 and L2, suggesting that the two indicators reflect similar constructs. Interestingly, the sentence verbal working memory demonstrated low correlations with other variables for the English-speaking children in the U.S. These low correlations indicate that the sentence repetition task measured the same qualities as other variables to some extent, but the overlapping is not conspicuous, suggesting that the sentence repetition task might measure a unique element of verbal memory skills.

No significant correlations were found for the Korean-speaking participants residing in Korea in between-language reading fluency and comprehension. This can be explained as the comparatively limited proficiency of L2 fluency and comprehension skills, compared to the acquired optimal level of L1 skills. The magnitude of the correlation coefficients among the variables was larger in the English L1 group in the U.S. One possible explanation for the weaker correlations in the Korean L1 children may be the fact that effects stemming from digit and sentence recall can mask the reading outcomes of L1 and L2 due to fewer demands imposed on phonological coding resulting from the shallow orthographic nature of Korean (Pae, 2011). As Gupta (1996) notes, phonological mapping appears to be related to the interaction between verbal memory and reading-related activities.

The Individual Contribution of Phonological and Verbal Memory to Reading Fluency and Comprehension for the English-Speaking Children (Research Question 1)

For the English-speaking children who were learning Korean as L2 in the U.S., phonological memory capacity, measured using the forward digit span task, played a salient role in English and Korean within-language reading fluency and comprehension. It also played a significant role in the prediction of cross-language reading fluency and comprehension. Digital verbal working memory, as indicated by the backward digit span task, played a significant role in English within-language reading fluency and comprehension as well as cross-language reading fluency and comprehension.

The pattern of findings can be explained in four ways. First, the weak relationship between verbal memory and reading comprehension in Korean can be attributable to the shallow orthography in which the grapheme-phoneme correspondence is transparent and regular. Since learners can easily decode words without problems, reading Korean may not necessitate a significant memory load for fluent reading. Second, reading English may be more challenging because English has a wider phonological repertoire than Korean.

Specifically, the orthographically deep characteristic affects English reading at the phonemic level, as a single grapheme can be pronounced differently according to neighboring graphemes. Third, English words have richer semantic representations than Korean, and are multidimensional in that many words carry multiple meanings. For example, English words have many homographs (e.g., *bat*, a baseball vs. *bat*, an animal) and homophones (e.g., *hi* vs. *high*; *whole* vs. *hole*, and heteronyms (e.g., *The wind is too strong* vs. *Wind the toy, and it will move*) (Pae, Greenberg, & Williams, 2011). Hence, the ability to activate task-relevant information and to inhibit incongruent information with the given syntactic and semantic coherence may be directly related to the ability to recall orally presented stimuli. This capability may also aid the child to build extended meanings on the basis of the root word and strengthen his/her word repertoire, because word knowledge can be broadened through a facilitation of effective verbal memory capability and a core phonological and semantic processing mechanism (Gupta, 1996). Lastly, the relationship between cross-language verbal working memory and reading seems to be more challenging than that in L1 and L2 within languages. Specifically, both L1 phonological and verbal working memory played a significant role in L2 reading fluency and comprehension for the English-speaking children. Since L2 has weaker connections to the mental lexicon and storage (Kroll & Stewart, 1994), higher cognitive loads and demands may be required for L2 than L1.

The Individual Contribution of Phonological and Verbal Memory to Reading Fluency and Comprehension for the Korean-Speaking Children (Research Question 2)

The results of hierarchical regression analyses showed different predictive patterns across sites. In general, the capability of recalling the immediate serial numbers dominantly served as a significant predictor for the English-speaking children. However, the magnitude of association between verbal memory capacity and reading fluency and comprehension diminished for the Korean-speaking counterparts. In Korean within-language reading, the predictor variables did not account for a significant variance in reading fluency and comprehension. For English within-language reading, phonological working memory explained only English reading fluency. The ability to form phonological representations of serially presented number stimuli seems to be important to read fluently in English. This may be because skills in phonological coding and quick retrieval facilitate word reading (Gathercole & Baddeley, 1989).

In a similar vein to the finding with the English-speaking children, cross-language reading seems to be more challenging for the Korean-speaking children. The L1 phonological working memory skills played a significant part in both L2 reading fluency and comprehension. This result indicates that reading fluency and comprehension development in L2 English is contingent upon children's ability to recall and efficiently retrieve phonological input. Since the representations of words stored in an individuals' memory are multifaceted, the ability to make use of the connections between phonological information and the given sentence may vary across learners.

Reading English and Korean

Variability in the ability to retain and manipulate serially presented digits seems to reflect the likelihood of success in reading fluency and comprehension because reading requires interrelated process skills, such as accessing stored information, selecting a relevant meaning on the basis of contextual information, and evaluating the appropriateness of the chosen meaning. Since the pronounceability of a new word is vital in word learning, phonological working memory seems to play a dominant role in L2 reading skills for Korean native children.

One possible explanation about the different dimension across the learner groups may be the linguistic features of the two languages that the learner groups speak on a daily basis. It is possible that the demand of phonological coding depends on the extent to which English requires in the process of grapheme-phoneme mapping. Attempts have been made in the literature to examine the features of lexical structures influencing visual processing or phonological mediation (Coltheart, Laxon, Keating, & Pool, 1986; Rastle & Coltheart, 1999). A shallow orthography, such as Korean, involves automatic and direct access to stored orthographic and phonological representations, while a deep orthography, such as English, goes through a phonologically mediated procedure (Stone & Van Orden, 1993). As such, the results of this study can be aligned with the explanation of direct access or phonologically mediated access to the mental storage in that reading English involves stronger phonological mediation due to the nature of a deep orthography than reading Korean (see Coltheart, Laxon, Keating, & Pool, 1986; Rastle & Coltheart, 1999 for details). Besides, verbal memory permits learners to store input sounds in a manner that allows for easy storage and retrieval from long-term memory depending on the linguistic characteristics in which children learn.

To summarize, developing L2 fluency and comprehension is a long-term process and a multifaceted construct, which involves phonological coding, encoding, appropriate verbal working memory processing, and semantic decoding. Due to the interplay of the variables, the function of verbal working memory and reading fluency and comprehension cannot be disregarded in L1 and L2 reading.

Limitations and Future Directions

The present study was unique with respect to a contrast between a Roman alphabetic language and the alphasyllabic language as well as an employment of two learning contexts (i.e., ESL and EFL contexts), while investigating the role of verbal memory in reading fluency and comprehension in L1 and L2. However, the following limitations are worthwhile to mention. First, the small sample size limited the statistical power of the inferential analyses. Second, the lack of standardized instruments across sites deter the generalization of this study's findings. It is necessary to have culturally and linguistically appropriate instruments in cross-language studies. Third, cultural variations in the two sites were not taken into account in the analyses and interpretation. Fourth, the potentially confounding effects of phonological complexity in English and Korean on the task were not examined. As the phonological and phonotactic structure of words is language-specific, the articulatory difficulty at the boundaries of the number of words pronounced in sequence needs to be taken into account. The phonological complexity of the numerals might have influenced the children's performance on the forward and backward digit span tasks. Lastly, there are still unanswered questions regarding the locus, nature, causality, and function of verbal memory in the development of L1 and L2 fluency and comprehension. A more systematic large-scale study would allow for an investigation to answer remaining questions.

Future studies examining the following are recommended. First, studies with a larger sample size will provide higher statistical power that will validate the findings of this study. Second, cross-cultural measurement development is needed to address complexities of two cultures, including cultural, contextual, linguistic differences, and to have valid psychometric properties to achieve measurement equivalence across the two groups. Third, since this study is a cross-sectional study, it cannot explain a developmental trajectory of the bilingual children in the two sites. A longitudinal study would offer an examination of children's dual-language learning and developmental trajectories in a systematic way.

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