Mapping Phonological Information from Auditory to Written Modality during Foreign Vocabulary Learning

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Learning to read in a foreign language often entails recognizing the printed form of words learned by sound. In the current study, the ability to map novel phonological information from the auditory modality onto the written modality was examined at different levels of overlap between the native language and an artificially constructed foreign language. In this study, monolingual English-speaking adults learned novel foreign words in the auditory modality. Recognition testing was first conducted in the auditory modality and then in the written modality. Participants who learned foreign words that matched English phonology showed similar accuracy rates when tested in either modality. Participants who learned foreign words that mismatched English phonology showed decreased recognition accuracy when tested in the written modality. Results indicate that cross-linguistic matching in phonology facilitated mapping of phonological information to the written modality. In addition, at different levels of cross-linguistic overlap, specific cognitive skills were found to correlate with the ability to map phonological information across modalities. This finding suggests that the cognitive skills required for acquisition of a foreign language may vary depending upon degree of cross-linguistic similarity.

Key words: **phonology; orthography; cross-linguistic overlap; foreign vocabulary learning; reading acquisition**

Introduction

Cross-linguistic similarity is an important variable in second-language acquisition, modulating the critical period phenomenon (De Keyeser, 2000) as well as the metacognitive advantage associated with knowing two languages (Bialystok, Majumder, & Martin, 2003). The ease of learning in situations in which the foreign linguistic system is similar to the native linguistic system is ascribed to the learner's reliance on L1 (first language) long-term memory representations. When the foreign phonological inventory is similar to the native language phonological inventory, a learner can rely on the established phonemic categories associated with the native language to process and integrate foreign language information. Studies examining the effect of cross-linguistic similarity on foreign vocabulary acquisition consistently demonstrate that phonological similarity across languages facilitates learning (Ellis & Beaton, 1993a; Gathercole, Willis, Emslie, & Baddeley, 1991). In addition, orthographic similarity across languages has been shown to facilitate foreign vocabulary acquisition (Ellis & Beaton, 1993b). For instance, Ellis and Beaton (1993a) demonstrated that the degree to which the foreign

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word conformed to the phonotactic patterns of the native language correlated highly with its "learnability." Similarly, Gathercole *et al.* (1991) found that nonwords that were structured in accordance with native-language phonotactic rules were more accurately repeated than nonwords that were not consistent with the native phonotactic system. Phonological similarity between the foreign and the native languages can facilitate acquisition because the learner can rely on long-term phonological knowledge to support learning (Gathercole & Baddeley, 1990; De Jong, Seveke, & Van Veen, 2000; Gathercole & Baddeley, 1990; Masoura & Gathercole, 1999; Papagno, Valentine, & Baddeley, 1991).

Because learning to read in a foreign language requires integration of novel phonological and orthographic information, it is likely that similarity in phonological and orthographic properties across L1 and L2 would facilitate reading acquisition in the second language. In situations in which the foreign language is similar to the native language, learners would be able to rely on long-term knowledge of orthography and phonology to support learning. Therefore, the first objective of the present study was to examine the effect of cross-linguistic similarity on acquisition of early reading in a foreign language. Early reading in a foreign language was operationally defined as participants' ability to map phonological information acquired in the auditory modality onto the written modality. It was hypothesized that cross-linguistic similarity would facilitate adults' ability to map phonological information from the auditory onto the written modality because it would enable reliance on native-language phonological and orthographic knowledge.

In addition to testing the effect of cross-linguistic similarity, we were also interested in cognitive skills that may underlie acquisition of early literacy in adults. Two general types of cognitive skills were considered: phonological capacity and vocabulary knowledge. Phonological abilities and vocabulary skills have consistently been identified as necessary for acquisition of reading in children (Corneau, Cormier, Grandmaison, & Lacroix, 1999) and adults (Cisero & Royer, 1995; Majeres, 2005) as well as for acquisition of foreign vocabulary (e.g., Cheung, 1996; Gathercole & Baddeley, 1990; Service, 1992; Service & Kohonen, 1995). For acquisition of reading by children, it has consistently been demonstrated that the more words a child knows, the easier it is for him or her to learn to read, since a greater number of words can be phonologically mapped and recognized. In fact, children's vocabulary skills are highly predictive of their ability to acquire print knowledge (Stahl & Fairbanks, 2006). Equally, if not more, important for acquisition of reading, are the child's phonological skills (Corneau *et al.,* 1999). Children who demonstrate superior phonological awareness tend to acquire the alphabetic reading principles with greater efficiency, since they are better able to rely on their phonological skills in mapping orthographic forms onto their phonological representations. For acquisition of reading in adults, it has also been shown that poor phonological skills result in less-accurate and less-efficient reading performance (e.g., Majeres, 2005).

For foreign word learning, research consistently demonstrates that higher scores on various phonological measures (e.g., nonword repetition, phoneme manipulation, etc.) are associated with increased retention of foreign vocabulary in both children (Gathercole & Baddeley, 1990; Service, 1992) and adults (Gupta, 2003; Papagno & Vallar, 1992, 1995; Speciale, Ellis, & Bywater, 2004). For instance, children with good nonword repetition skills are consistently found to outperform their poor nonword repetition peers when learning novel words (Cheung, 1996; Gathercole & Baddeley, 1990; Service, 1992; Service & Kohonen, 1995). In primary school students, repetition accuracy for nonwords in a second language predicts learning of vocabulary of the second language (Service, 1992). Similarly, Gathercole and Baddeley (1989) found that children's short-term memory span (e.g., the ability to repeat nonwords) is highly predictive of their vocabulary size one year later.

Phonological short-term memory also contributes to foreign language learning in adults. For instance, the role of phonological short-term memory in adult word learning has been supported by findings of Gupta (2003), Papagno and Vallar (1995), and Speciale *et al.* (2004), but results of the three studies did not completely converge. Papagno and Vallar (1995) demonstrated that nonword repetition correlated highly with participants' word learning performance. Gupta (2003) also demonstrated a correlation between nonword repetition performance and word learning in adults; however, when digit span performance was partialed out, correlations between nonword repetition and word learning failed to reach significance. In contrast, Speciale *et al.* (2004) found that nonword repetition correlated with participants' ability to learn L2 words, but only when participants produced the novel word in response to its native-language translation. When the direction of testing changed (i.e., participants had to produce native-language translations for novel words), nonword repetition scores were not related to performance. The role of phonological memory in adult word learning may also vary across age groups. For instance, Service and Craik (1993) examined word learning in younger and older participants and found that older, but not younger, adults showed a strong relationship between repetition performance for unfamiliar words (indexing phonological short-term memory) and word learning.

While phonological short-term memory skills are fundamental for acquisition of foreign-language vocabulary, vocabulary abilities in the native language have also been linked with second-language acquisition. For children, Masoura and Gathercole (1999) showed that the ease of L2 vocabulary learning is strongly influenced by the stability and extent of representations in L1 vocabulary. For adults, recent studies have found that adults who acquired the second language after the critical period are capable of achieving near-native performance in the foreign language if they possess high verbal ability in their native language (De Keyeser, 2002).

Given the role of phonological memory and vocabulary knowledge in acquisition of a foreign language and in acquisition of reading, it is likely that the same skills would underlie acquisition of early literacy in the foreign language. However, the extent of involvement of phonological memory and vocabulary knowledge in the learning process may vary according to how much L1 and L2 overlap. For instance, previous work suggests that phonological capacity may be especially important for learning phonologically unfamiliar foreign words (De Jong, Seveke, & Van Veen, 2000; Papagno *et al.*, 1991). Children with poor nonword repetition skills were shown to be slower at learning phonologically unfamiliar names for toys, but not at learning familiar names for them (Gathercole & Baddeley, 1990). Similarly, in children older than 5 years of age, phonological sensitivity (i.e., the ability to detect and manipulate sound units in words) contributed to learning novel names with unfamiliar phonological structure, but not to learning familiar names (De Jong, Seveke, & Van Veen, 2000). Further, nonword repetition scores predicted knowledge of foreign, but not of native vocabulary (Masoura & Gathercole, 1999). Together, these findings suggest that phonological skills and L1 vocabulary influence L2 acquisition and affect foreign word learning differently, depending on the extent of cross-linguistic overlap between the native and the foreign languages.

In the current research, acquisition of early reading skills in a foreign language was examined within the context of a foreign vocabulary learning task. The objective of the present study was to examine adults' ability to map phonological information from the auditory modality onto the written modality at different levels of cross-linguistic overlap. It was expected that cross-linguistic similarity would modulate participants' ability to map phonological information across modalities. It was also expected that phonological short-term memory and vocabulary knowledge would influence adults' ability to map phonological information across modalities. Since the ability to map phonological information onto the written modality is an important component of literacy acquisition in the second language, we were also interested in the role of native-language reading skills. Therefore, three types of cognitive measures were considered: phonological short-term memory (as measured by digit span and nonword repetition), native-language vocabulary knowledge (as measured by receptive and expressive vocabulary), and reading skills in the native language (as measured by a reading fluency test).

Cross-linguistic overlap was manipulated by creating four artificial languages that shared different degrees of phonemic and alphabetic overlap with English. Four versions of artificial vocabulary items were constructed to (1) match both the phonological system and the orthographic systems of English (+P+O); (2) mismatch the phonological, but match the orthographic system of English (−P+O); (3) match the phonological, but mismatch the orthographic system of English (+P−O); and (4) mismatch both the phonological and the orthographic systems of English (−P−O). English-speaking monolingual adults were assigned to one of four groups, with participants in each group learning a different version of the foreign vocabulary using the Paired Associate Learning (PAL) paradigm (Van Hell & Mahn, 1997), in which a novel word is paired with its native-language translation. Participants in each of the four groups learned vocabulary items in the auditory modality. Retention of novel vocabulary items was first tested in the auditory modality and then in the written modality.

It was hypothesized that cross-linguistic overlap, phonological skills, and vocabulary abilities would be associated with adults' ability to map phonological information across modalities. It was predicted that:

(1) Cross-linguistic similarity would facilitate participants' ability to map phonological information from the auditory modality onto the written modality;
(2) Better performance on cognitive measures of phonological memory and L1 vocabulary would lead to improved ability to map phonological information onto the written modality; and
(3) Mapping of phonological information onto the written modality would be supported by phonological memory and L1 vocabulary differently, depending on the extent of cross-linguistic overlap between the native and the foreign language.

Methods

The study followed a three-way mixed design in which the within-subjects independent variables were modality of testing (auditory versus written) and testing session(immediate versus delayed), and the between-subjects independent variable was group (+P+O, −P+O,+P−O, and −P−O). Dependent variables intended to capture the success of vocabulary learning included both accuracy and reaction time (RT) measures. Accuracy of recognition was defined as proportion correct in selecting the appropriate response out of five available choices. Efficiency of recognition (reaction times) was defined as the response latency for selection of the correct translation.

Participants

Ninety-six monolingual speakers of English (mean age = 23 years, 11 months; SD = 0.83 years) were randomly assigned to one of four groups (+P+O; −P+O; +P−O; and −P−O). Groups did not differ in age, education level, gender distribution, vocabulary knowledge (Peabody Picture Vocabulary Test, 3rd edition, Dunn & Dunn, 1997; Expressive Vocabulary Test, Williams, 1997), or performance on standardized measures of short-term phonological memory (digit span and nonword repetition sub-test of the Comprehensive Test of Phonological Processing (Wagner, Torgesen, & Rashotte, 1999).

Materials

Four versions of artificial foreign vocabulary items were constructed. Each of the versions consisted of eight sounds (and their associated letters). Four sounds and letters corresponded to English (in order to ease the vocabulary learning process), and four varied across vocabulary versions in their similarity to English (in order to test the effect of cross-linguistic overlap). The four English phonemes included two vowels (/^/-A and /e/-E) and two consonants (/f/-F and /n/-N). The remaining four phonemes, two vowels and two consonants, were manipulated across the four vocabulary versions, so that in versions +P+O and +P−O they remained English (/i/, /u/, /t/, /g/), but in versions −P+O and −P−O they were replaced with non-English phonemes. The non-English phonemes were selected to be perceptually different from all existing English phonemes and yet to be pronounceable by native speakers of English. In order to rule out confounds associated with articulatory difficulties, the non-English phonemes shared place of articulation with the English phonemes. The non-English phonemes in the stimuli for −P conditions were taken from languages other than English (French, Russian, Urdu, and Hebrew). The vowels /i/ and /u/ were replaced by the non-English vowels /I/ and /y/, respectively, while the consonants /t/ and /g/ were replaced by the non-English consonants /T/ and /χ^2/, respectively. Further, four English letters were manipulated across vocabulary versions, so that they remained English for versions +P+O and −P+O, but were replaced with non-English symbols for versions +P−O and −P−O. The non-English letters used to spell foreign words in −O conditions were selected on the basis of their similarities (in terms of number of elements) to the English letters they replaced. For instance, the letter T and the corresponding non-English symbol both consist of two crossing strokes. The non-English letter symbols were drawn from rare languages (Bassa, Albanian, N'Ko) in order to rule out familiarity effects. None of the participants reported familiarity with these letters.

Twenty-four monosyllabic and disyllabic nonwords corresponding to both English phonology and English orthography were constructed. All nonwords were recorded by a native English-speaking male audiologist, who was extensively trained on the nonwords' pronunciation prior to the recording session. Each nonword was paired with its English "translation." All 24 English translations referred to concrete, highly imageable objects with frequent English names. The English words were on average 4.51 (SE = 0.52) letters in length with an average of 47.79 (SE = 56.24) words/million frequency of use, 578.38 (SE = 35.71) concreteness rating, 593.58 (SE = 30.15) imageability rating, and 547.50 (SE = 35.84) familiarity rating. Frequency ratings (Francis & Kucera, 1982) as well as concreteness, imageability, and familiarity ratings (Gilhooly & Logie, 1980; Paivio, Yuille, & Madigan, 1968; Toglia & Battig, 1978) for English words were obtained using the MRC Psycholinguistic Database. The nonwords were three to five phonemes in length, with an average phoneme frequency of 1.14 (SE = 0.06), an average biphone frequency of 1.00 (SE = 0.003), an average bigram frequency of 4951.92 (SE = 2925.51), and had an average 1.04 (SE = 1.99) orthographic neighbors.

Procedure

Alphabet Learning

At the beginning of the experimental session, each participant was taught the sounds and the corresponding letters of the foreign language. Each letter appeared on the computer screen, and the corresponding sound was played twice over the headphones. The participant was instructed to repeat the sound out loud three times. After all letters and sounds had been presented, the participant was asked to match each sound to the appropriate letter and to pronounce each sound when presented with a letter. All participants were 100% accurate in producing the correct sounds for the letters at the end of the alphabet-learning sequence.

Vocabulary Learning

Participants heard the novel word pronounced twice over the headphones and saw its written English translation on the right side of the computer screen. The participants were instructed to repeat the novel word and its English translation out loud three times. Each pair was presented twice during the learning phase. Learning was self-paced.

Immediate Vocabulary Testing

After the vocabulary-learning phase, the participant's memory for presented items was tested using both an auditory and a written recognition task. During auditory recognition, participants heard foreign words over headphones and chose the correct English translations from five alternatives listed on the computer screen as fast as possible. Of the five alternatives, one answer was correct, two answers were translations of foreign words from the same list, one answer was an English word that was semantically related to the correct answer, and one answer was an unrelated English word not previously presented. Immediately after completing the auditory recognition test, participants completed the written recognition test. During the written recognition test, participants saw foreign words spelled out on the computer screen and chose the correct English translation from five alternatives. The alternatives were the same choices offered to the participants during auditory testing and they were presented in the same order as during the auditory testing. Therefore, performance on the written test indicated the accuracy and the speed with which participants could map newly learned phonological information onto the written modality.

Delayed Vocabulary Testing

One week after the initial learning session, participants returned to the laboratory and were tested on long-term retention of the learned vocabulary. Participants completed both the auditory and the written recognition tasks in the same manner as during immediate testing.

Standardized Assessment of Short-Term Memory and Vocabulary Knowledge

After delayed testing was completed, participants were given standardized assessment measures of vocabulary knowledge and phonological short-term memory. Phonological short-term memory was measured using two tests: the digit span test and the nonword repetition test (Comprehensive Test of Phonological Processing; Wagner, Torgesen, & Rashotte, 1999). Native-language vocabulary knowledge was measured using two standardized tests, the Peabody Picture Vocabulary Test, 3rd edition (PPVT; Dunn & Dunn, 1997), which measured receptive vocabulary, and the Expressive Vocabulary Test (EVT; Williams, 1997), which measured expressive vocabulary. In addition, a reading fluency test was administered that required participants to read sentences and judge their content for veracity (Woodcock–Johnson Tests of Achievement). Tests were administered in the following order: (1) PPVT, (2) EVT, (3) reading fluency, (4) digit span, and (5) nonword repetition.

Data Analyses

For each measure, univariate analyses of variance (ANOVAs) were conducted, with group (+P+O,−P+O,+P−O,−P−O) as a between-subjects independent variable. Next, accuracy and reaction time data for each group were analyzed using repeated-measures ANOVAs, comparing performance on the written recognition test to performance on the auditory recognition test, both immediately after learning and during delayed testing.

In addition, a difference score between performance on the written test and performance on the auditory test was determined for each group (score on written testing minus score on auditory testing). This difference score reflected the gain or drop in accuracy rates or reaction times with repeated testing in a different modality. For accuracy rates, a score above zero reflected higher accuracy rates on the written testing than on the auditory testing, and a score below zero reflected lower accuracy rates on the written testing than on the auditory testing. For reaction times, a lower difference score reflected shorter reaction times on written testing in relation to auditory testing. Therefore, a successful learner capable of transferring phonological information from the auditory modality into the written modality would receive a higher difference score for accuracy and a lower difference score for RT. Correlation analyses between cognitive measures and difference scores were conducted in order to examine which cognitive skills might underlie the ability to transfer phonological information across modalities at different levels of cross-linguistic overlap.

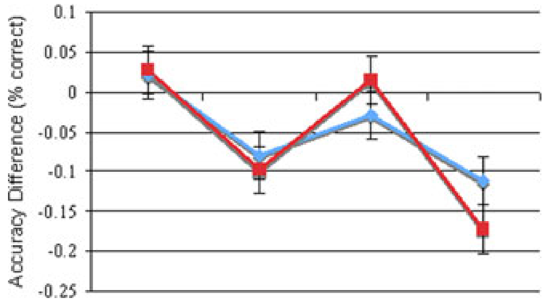

Figure 1. Accuracy difference scores (written testing minus auditory testing) for each group (+P+O; −P+O; +P−O; −P−O), during immediate (*solid circle*) and delayed (*solid square*) testing.

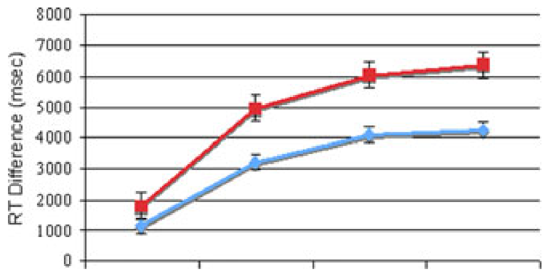

Figure 2. RT difference scores (written testing minus auditory testing) for each group (+P+O; −P+O; +P−O; −P−O), during immediate (*solid circle*) and delayed (*solid square*) testing.

Results

Between-Group Differences in Recognition Performance

To examine between-group differences in recognition performance as a function of cross-linguistic overlap, accuracy rates and reaction times were examined using univariate analyses of variance with group (+P+O;−P+O;+P−O;−P−O) as a between-subjects independent variable. Table 1 shows the accuracy rates (means and standard deviations) for each group and testing condition. Table 2 shows the reaction times (means and standard deviations) for each group and testing condition.

During written testing, significant between-group differences were observed for accuracy rates during both immediate $F(3, 89) = 5.30$, $P < 0.01$, $\eta_p^2 = 0.15$ and delayed testing, $F(3, 86) = 3.95$, $P < 0.05$, $\eta_p^2 = 0.12$. Post-hoc analyses revealed that participants in the +P+O group were more accurate than participants in the −P+O group and than participants in the −P−O group, all least-significant P values < 0.05 (Table 1). Similarly, participants in the +P−O group were more accurate than participants in the −P+O group and than participants in the −P−O group, all least-significant P values < 0.05. These findings indicate that participants were more accurate at mapping phonology onto orthography in a new language if the foreign-language phonology matched native-language phonology.

TABLE 1. Recognition Accuracy Rates for Written and Auditory Testing

Group	Auditory testing mean (SE)	Written testing mean (SE)	Between-group comparisons (for difference scores)		
			+P+O	−P+O	+P−O
+P+O	0.77 (0.03)	0.79 (0.03)	–		
−P+O	0.71 (0.04)	0.63 (0.04)*	*P* < 0.05	–	
+P−O	0.78 (0.04)	0.75 (0.05)	n.s.	n.s.	–
−P−O	0.71 (0.03)	0.60 (0.04)*	*P* < 0.05	n.s.	*P* < 0.05
			+P+O	−P+O	+P−O
+P+O	0.66 (0.04)	0.66 (0.04)	–		
−P+O	0.55 (0.04)	0.54 (0.04)	n.s.	–	
+P−O	0.63 (0.04)	0.67 (0.03)	n.s.	n.s.	–
−P−O	0.61 (0.04)	0.55 (0.03)	n.s.	n.s.	*P* < 0.05

Note: A significant difference between written and auditory recognition accuracy is marked by an asterisk next to the written testing mean (SE)*, indicating a $P < 0.05$.

TABLE 2. Recognition Reaction Times for Written and Auditory Testing

Group	Auditory testing mean (SE)	Written testing mean (SE)	Between-group comparisons (for difference scores)		
			+P+O	−P+O	+P−O
+P+O	3305.48 (215.79)	4420.92 (229.90)*	–		
−P+O	3320.45 (277.27)	6531.72 (471.64)*	*P* < 0.05	–	
+P−O	3105.93 (166.21)	7217.44 (733.68)*	*P* < 0.05	n.s.	–
−P−O	2964.17 (128.60)	7216.96 (515.01)*	*P* < 0.05	n.s.	n.s.
			+P+O	−P+O	+P−O
+P+O	3431.80 (182.27)	4095.69 (252.50)*	–		
−P+O	3238.67 (234.24)	4982.54 (352.15)*	*P* < 0.05	–	
+P−O	3607.07 (261.63)	5530.68 (364.45)*	*P* < 0.05	n.s.	–
−P−O	3430.06 (203.92)	5538.95 (339.56)*	*P* < 0.05	n.s.	n.s.

Note. A significant difference between written and auditory recognition RT is marked by an asterisk next to the Written Testing Mean (SE)*, indicating a $P < 0.05$.

In addition to accuracy differences, significant between-group differences were also observed for *reaction times*, both during immediate written testing, $F(3, 89) = 6.74$, $P < 0.001$, $\eta_p^2 = 0.19$ and during delayed written testing, $F(3, 86) = 4.35$, $P < 0.01$, $\eta_p^2 = .43$. Participants in the +P+O group were faster than participants in the −P+O group, +P−O group, and −P−O group, all least significant *P* values<0.01 (Table 2).

During auditory testing, results revealed comparable *accuracy* and *reaction time* rates across the four groups for both immediate and delayed testing, $P > 0.1$.

Within-Group Differences in Recognition Performance

To examine within-group differences in recognition performance as a function of testing modality, accuracy, and reaction time measures were analyzed using repeated-measures ANOVAs. For the +P+O group, repeated-measures ANOVAs revealed comparable accuracy rates for auditory and written testing, both immediately after learning, $F(1, 23) = 0.82$, $P = 0.37$, $\eta_p^2 = 0.04$, and during delayed testing, $F(1, 22) = 0.06$, $P = 0.82$, $\eta_p^2 = 0.003$. Conversely, analyses revealed longer reaction times during written than during auditory testing, both immediately after learning, $F(1, 23) = 56.32$, $P < 0.001$, $\eta_p^2 = 0.71$, and at delayed testing, $F(1, 22) = 16.81$, $P < 0.001$, $\eta_p^2 = 0.43$. Thus, participants in the +P+O group were slower, but not less accurate, when tested in the written modality than when tested in the auditory modality.

For the −P+O group, repeated-measures ANOVAs revealed that when tested immediately after learning, participants were less accurate when tested in the written modality than in the auditory modality, $F(1, 22) = 12.89$, $P < 0.01$, $\eta_p^2 = 0.37$. However, testing-modality differences disappeared with delayed testing, $F(1, 20) = 0.37$, $P = 0.55$, $\eta_p^2 = 0.02$, and participants were just as accurate during written as during auditory testing. RT analyses revealed longer reaction times during written than during auditory testing, both immediately after learning, $F(1, 22) = 91.80$, $P < 0.001$, $\eta_p^2 = 0.81$, and at delayed testing, $F(1, 20) = 31.42$, $P < 0.001$, $\eta_p^2 = 0.61$. Thus, participants in the −P+O group were slower, and less accurate, when tested in the written modality than when tested in the auditory modality.

For the +P−O group, repeated-measures ANOVAs revealed comparable accuracy rates for the auditory and the written testing, both immediately after learning, $F(1, 22) = 1.67$, $P = 0.21$, $\eta_p^2 = 0.07$, and during delayed testing, $F(1, 22) = 2.19$, $P = 0.15$, $\eta_p^2 = 0.09$. Conversely, analyses revealed longer reaction times during written than during auditory testing, both immediately after learning, $F(1, 22) = 40.82$, $P < 0.001$, $\eta_p^2 = 0.65$, and at delayed testing, $F(1, 22) = 66.87$, $P < 0.001$, $\eta_p^2 = 0.75$. Thus, similar to participants in the +P+O group, participants in the +P−O group were slower, but not less accurate, when tested in the written modality than when tested in the auditory modality.

For the −P−O group, repeated-measures ANOVAs revealed that when tested immediately after learning, participants were less accurate when tested in the written modality than in the auditory modality, $F(1, 22) = 11.76$, $P < 0.01$, $\eta_p^2 = 0.35$. This testing-modality difference attenuated and became marginal with delayed testing, $F(1, 22) = 3.57$, $P = 0.07$, $\eta_p^2 = 0.14$, but participants remained less accurate at written than at auditory testing. Similarly, analyses revealed longer reaction times during written than during auditory testing, both immediately after learning, $F(1, 22) = 91.85$, $P < 0.001$, $\eta_p^2 = 0.81$, and at delayed testing, $F(1, 22) = 72.30$, $P < 0.001$, $\eta_p^2 = 0.77$. Thus, participants in the −P−O group were slower, and less accurate when tested in the written modality than when tested in the auditory modality.

Relating Cognitive Abilities and Recognition Performance

Correlation analyses were used to examine which cognitive skills would be associated with the ability to map phonological information from the auditory modality onto the written modality. Participants' performance on cognitive measures was correlated with the difference scores between the written and the auditory testing modalities. Because a higher difference score for accuracy would indicate better performance on written compared to auditory testing, positive correlations between cognitive measures and accuracy difference would indicate that better performance on the cognitive test was associated with a better ability to map phonological information across modalities. Conversely, because a higher difference score for RT would indicate less efficient performance on written testing, positive correlations between cognitive measures and RT difference would indicate that better performance on cognitive measures was associated with a lower ability to map phonological information across modalities.

In the +P+O group, no significant correlations were observed among any of the cognitive measures and difference scores obtained immediately after learning for accuracy or RTs. For delayed testing, RT difference correlated negatively with expressive vocabulary (EVT $R = -0.39$, $P = 0.06$), indicating that higher vocabulary knowledge was associated with more efficient mapping of phonological information onto the written modality. RT difference also correlated positively with performance on the digit span measure of phonological memory ($R = 0.40$, $P = 0.05$), indicating that a larger digit span was associated with less efficient mapping of phonological information onto the written modality. Difference scores between written and auditory testing for each group are presented in Figure 1 (accuracy) and Figure 2 (reaction times).

In the −P+O group, significant correlations were observed between the digit span measure of phonological memory and accuracy difference scores, both immediately after learning ($R = -0.46$, $P < 0.05$) and during delayed testing ($R = -0.45$, $P < 0.05$), indicating that a larger digit span was associated with less accurate mapping of phonological information from the auditory modality onto the written modality. A similar inverse relationship was observed between the accuracy difference score and the reading fluency measure during delayed testing ($R = -0.70$, $P < 0.01$), suggesting that participants with higher reading fluency scores were less accurate at mapping phonological information onto the written modality. Interestingly, the nonword repetition measure of phonological memory correlated positively with accuracy difference scores during delayed testing ($R = 0.52$, $P < 0.05$), suggesting that participants with a higher phonological short-term memory span tended to be more successful at mapping newly learned phonological information onto the written modality.

For the +P−O group, RTdiff-erence scores during delayed testing correlated negatively with expressive vocabulary (EVT $R = -0.42$, $P < 0.05$) and with nonword repetition ($R = -0.48$, $P < 0.05$); no other significant correlations were observed. This suggests that better vocabulary knowledge and phonological short-term memory skills were associated with more efficient mapping of phonological information from the auditory onto the written modality.

For the −P−O group, only one marginally significant correlation was observed between reading fluency and RT difference scores immediately after learning ($R = -0.50$, $P = 0.059$), suggesting that higher reading fluency scores were associated with more efficient mapping of phonological information onto the written modality.

Discussion

Learning to read in a foreign language often entails recognition of printed words originally acquired in the auditory modality. This recognition relies on the ability to map phonological representations across modalities (auditory to written). In the current research, adults' ability to map phonological information from the auditory onto the written modality was examined within the context of a foreign-word learning task. We aimed to explore whether the underlying cognitive skills that may support mapping of phonological information from the auditory onto the written modality would vary, depending on the degree of cross-linguistic similarity between the native and the foreign language.

Cross-Linguistic Similarity in Foreign Vocabulary Learning

Results revealed that cross-linguistic overlap mediated adults' ability to map phonological information across modalities. Specifically, adults found it easier to map phonological information onto the written modality when it matched the phonology of their native language (+P+O and +P−O groups) than when it mismatched the phonology of their native language (−P+O and −P−O groups). Switching modalities at testing carried efficiency costs for all participants, but accuracy costs were observed only for participants who acquired a phonologically mismatching foreign language (−P+O and −P−O).

The role of cross-linguistic similarity in foreign vocabulary acquisition has been substantiated by previous research (Ellis & Beaton, 1993a; Gathercole *et al.*, 1991). The current work suggests that cross-linguistic similarity also plays an important role in participants' ability to transfer phonological information across modalities (auditory to written). This ability is fundamental for literacy acquisition in a foreign language, and the results of this research suggest that phonological similarity between L1 and the foreign language makes this task easier. Interestingly, phonological, but not orthographic similarity across languages facilitated participants' performance. Thus, participants who acquired a foreign language that mismatched L1 in orthography, yet matched it in phonology (+P−O), maintained their accuracy of mapping a foreign word to its English translation when tested in the written modality. Conversely, participants who acquired a phonologically mismatching foreign language showed accuracy costs when testing modality switched from auditory to written. It is possible that this is due to the initial weak encoding of phonologically mismatching information and not to difficulty mapping phonological information onto a different modality. However, the fact that all four groups of participants demonstrated comparable accuracy rates on auditory testing indicates that participants retained comparably strong phonological representations across the four groups. Thus, it is more likely that the difficulty observed during written testing for participants in the −P+O and −P−O groups was due to a more effortful mapping of phonologically unfamiliar information onto the corresponding orthography and not to the less-robust representation of phonological information.

The Relationship between Measures of Cognitive Function and Foreign Vocabulary Learning

Results revealed that different sets of cognitive skills were associated with adults' ability to map phonological information across modalities, and patterns of correlation depended on the degree of cross-linguistic overlap between the native and the foreign languages. Specifically, better vocabulary knowledge in L1 led to better ability to map phonological information across modalities, but only when L1 and the foreign language shared phonology (+P+O and +P−O groups). Interestingly, we found distinct correlation patterns between word-learning performance and the two phonological memory measures (the digit span and the nonword repetition). Higher performance on the digit span measure led to less efficient and/or less accurate mapping of phonological information across modalities in cases in which participants learned a foreign language that matched L1 in orthography (+P+O and −P+O groups). Conversely, higher nonword repetition performance was positively associated with adults' ability to map phonological information across modalities, but only for groups who learned a foreign language that mismatched L1 in either phonology (−P+O) or orthography (+P−O).

The finding that better L1 vocabulary skills led to better recognition performance is consistent with previous studies showing that native-language vocabulary becomes an important predictor of foreign word learning (Masoura & Gathercole, 1999). Better vocabulary skills in the native language can support further word learning, since new words can be incorporated into the existing system with greater ease. Note that vocabulary skills were associated with performance only by participants who acquired foreign languages that matched L1 in phonology and were not associated with performance by participants in phonologically mismatching groups. This pattern is likely due to the fact that L1 vocabulary knowledge is indicative of the strength of lexical-level phonological representations. When a foreign word fits the phonology of the native language, the native-language phonological lexicon can support learning; however, when the foreign word does not fit the phonology of the native language, the native-language phonological lexicon cannot support learning. This differential impact of L1 vocabulary on participants' ability to map phonology across modalities suggests that native-language vocabulary can support further language learning, but only when the phonological systems of the two languages are aligned.

The finding that higher nonword repetition scores led to better performance for the −P+O and the +P−O groups is consistent with a number of previous studies showing that phonological short-term memory skills are predictive of foreign word-learning performance (Gathercole & Baddeley, 1990; Gupta, 2003; Speciale *et al.*, 2004). In the current study, better ability to maintain the phonological shape of the foreign word in working memory (nonword repetition score) led to better ability to map this phonological representation onto a different modality. Interestingly, this relationship was observed only for situations when the foreign language mismatched the native language in one of the parameters—phonology or orthography. The finding that nonword repetition scores predicted learning in the phonological mismatch condition is consistent with previous studies showing stronger contribution of phonological short-term memory to learning unfamiliar foreign words than to learning familiar foreign words (De Jong, Seveke, & Van Veen, 2000; Papagno *et al.*, 1991). While acquisition of phonologically familiar foreign words is supported by long-term phonological knowledge, acquisition of phonologically unfamiliar foreign words must rely entirely on one's phonological short-term memory (Papagno *et al.*, 1991). Moreover, in the current study, nonword repetition scores were also associated with learning in the orthographic mismatch condition. It is possible that in situations of mismatch (phonological or orthographic), one's capacity for maintaining phonological information in short-term memory is especially important for mapping across modalities. However, when both foreign phonology and orthography match that of the native language, it may be unnecessary to maintain the phonological shape of the word in working memory, since it can be easily reconstructed online when presented with the orthographic shape of the word. In a situation when neither foreign phonology nor orthography match that of the native language, one's skill in maintaining the phonological shape of the word in working memory may not be sufficient to facilitate mapping onto the novel orthography. The task of mapping unfamiliar phonology onto unfamiliar orthography may draw upon a set of skills that is distinct from those relied on when the two languages overlap in at least one dimension. Lack of significant correlations between recognition performance and cognitive skills for the −P−O group supports this notion and suggests the need to explore cognitive skills other than those tested here.

In contrast to nonword repetition performance, digit span performance correlated negatively with participants' ability to map phonological information across modalities, but only for foreign languages that matched L1 in orthography (+P+O and −P+O). It is possible that the inverse relationship between the digit span and performance accuracy is driven by the mismatch between phonological information maintained in working memory and the phonological information activated during written testing. In both the +P+O and the −P+O conditions, orthographic information presented during written testing consisted of familiar English letters. Because of the firm bidirectional connections that exist between letters and phonemes in the native-language (Seidenberg & McClelland, 1989; Van Orden & Goldinger, 1994), it is likely that orthographic information presented at testing activated native-language phonology. This phonology was likely to conflict with phonology remembered by participants (since the foreign words in the −P+O condition contained non-English phonemes). Participants with high digit span may have been more capable of remembering phonological information associated with auditorily learned foreign words than participants with low digit span. This high phonological capacity may have led high digit span participants to activate the remembered phonological representation during testing. However, the remembered phonology would conflict with phonological representations activated during written testing, resulting in less-successful written recognition performance in high digit span participants. While this account can explain the findings in the −P+O group, it is less clear why an inverse relationship between digit span and reaction times would be obtained in the +P+O condition. The ability to maintain phonological information in the working memory should help participants map phonological information onto the written modality, not hinder it. One explanation for this observed pattern is a possibility that phonological information activated via orthography did not exactly match phonological information acquired during auditory learning. In the +P+O foreign language constructed for the present study, the mappings between letters and phonemes were always consistent. For example, the vowel /a/ was always pronounced as /ˆ/. This is not the case in English, however, where the closed-syllable /a/ often maps onto the phoneme /æ/. It is possible that such inconsistencies in mappings between letters and phonemes of L1 and the foreign language led to the observed negative correlation between the digit span and the recognition performance in the +P+O group.

The distinct correlation patterns between participants' ability to map phonological information across modalities, on the one hand, and nonword repetition and digit span, on the other hand, suggests that nonword repetition and digit span performance may reflect different sub-components of working memory. It is possible that nonword repetition is more reflective of sublexical phonological abilities, while digit span is more reflective of lexically based phonological memory. It is also possible that digit span incorporates a sizable sequencing component with performance reflective not only of one's ability to maintain phonological information in short-term memory, but also one's ability to maintain it in a very specific order (Gupta, 2003). By this logic, successful performance on a nonword repetition task requires less of a sequencing ability than successful performance on a digit span task. This difference between the tasks cannot explain, however, why the two load differently and inversely onto participants' ability to map phonological information across modalities, and future studies may examine this question.

Conclusions

In sum, results of the current study suggest a pattern of complex interactions between adults' ability to map phonological representations across modalities, cross-linguistic similarity, and underlying cognitive skills. It appears that phonological similarity across the native and the foreign languages facilitates one's ability to map phonological information onto a new modality and that vocabulary knowledge in the native language supports this ability. In general, the findings of the current study suggest that adult acquisition of early literacy in different foreign language systems is associated with distinct sets of skills and depends, to a large extent, on the overlap between the phonological and the orthographic inventories in the native and the foreign languages.

Future work may examine more closely the developmental course of the interplay between cross-linguistic similarity and cognitive skills. For that, language learning would have to be examined in a long-term fashion (i.e., retention over longer periods of time) as well as for other linguistic structures (e.g., morphology, syntax). A more immediate goal may be to perform a large-scale study that would employ factor analysis to examine whether word learning would cluster with the digit span measure of phonological memory or with the nonword repetition measure of phonological memory as well as whether the clustering patterns would depend on the degree of cross-linguistic overlap between the native language and the foreign language.

This research has implications for clinical and education practices with second-language learners and bilingual populations as well as with adult speakers who have difficulty reading in their native language. Findings suggest that a core set of cognitive skills may underlie reading acquisition. It is possible that improving those skills may indirectly affect reading. For instance, improving an English as a second language (ESL)-speaker's native-language vocabulary may facilitate his or her reading acquisition. However, results indicate that the link between reading acquisition and L1 vocabulary knowledge relies on shared phonology between L1 and L2. Therefore, improvement in vocabulary skills may be less helpful for literacy acquisition in a phonologically mismatching language. Instead, improving one's phonological memory may carry greater benefits in situations in which the foreign language mismatches the native language in phonology.

To conclude, foreign language learning and acquisition of reading need to be considered within a larger, interactive framework. For instance, previous work showed that while vocabulary skills influence acquisition of early literacy, as reading becomes automatic, reading skills predict vocabulary growth. Similarly, while phonological skills influence one's ability to acquire foreign words, as foreign language knowledge progresses, bilinguals' phonological capacity increases. The present study shows that phonological capacity, vocabulary knowledge, and cross-linguistic similarity are three variables that not only influence learning outcomes, but also mutually influence each other. Together, these findings support an interactive, dynamic account of vocabulary and literacy acquisition in a second language.

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Conflicts of Interest

The authors declare no conflicts of interest.

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