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Chinese-English bilinguals transfer L1 lexical reading procedures and holistic orthographic coding to L2 English

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ABSTRACT

This study examines second language (L2) reading by individuals with a Chinese or Korean native literacy (L1) background. It tests a hypothesis about the L1-L2 transfer of word reading procedures, which predicts that Chinese-English (CE) bilinguals transfer a bias towards lexical reading procedures and holistic orthographic coding to L2 English reading, whereas Korean-English (KE) bilinguals transfer a bias towards sublexical reading procedures and analytic orthographic coding. To test this hypothesis, we gave a word naming task to CE and KE groups matched on English language experience and use. The stimuli were English words that varied in frequency and orthographic-phonological consistency, and pronounceable English nonwords. Items were presented in an upright or inverted orientation. The CE bilinguals exhibited slower naming latencies, especially for inverted stimuli. Further, the effects of inversion interacted differently with frequency and consistency across the two groups, with CE bilinguals more sensitive to frequency and KE bilinguals more sensitive to consistency. Group differences in naming accuracy were also observed, even when differences in reading skill were taken into account. Overall, these findings provide evidence for L1-L2 transfer of word reading procedures and demonstrate that stimulus inversion can unmask individual differences in reading style. More generally, they indicate that both lexical and sublexical procedures can support skilled English reading, though the pace of reading development will likely be poorer for readers biased towards lexical reading procedures.

1. Introduction

The typical adult reader can recognize thousands of printed words with little conscious effort. Recognition of a printed word occurs when the orthographic, phonological, and semantic information that together uniquely identifies the printed word is accessed and interrelated. This conjoint activation of lexical constituents is a fundamental principle of word identification. The procedures that underlie successful word identification can be broadly classified as operating at the lexical (word) or sublexical (sub-word) level. The degree to which word identification is reliant upon a lexical or sublexical procedure can vary considerably across items, writing systems, and individuals. The theoretical and practical importance of this variability has driven efforts to understand and model its

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causes and consequences. Importantly, these efforts have occurred nearly exclusively within the context of native language literacy. Consequently, little is known about how an individual's native language and literacy experiences (L1) shapes literacy in a second language (L2).

The current study tackles this issue. Specifically, it compares the reading performance of Chinese-English (CE) bilinguals, who come from a non-alphabetic L1, to that of Korean-English (KE) bilinguals, who come from an alphabetic L1. An assimilation theory of L1-L2 transfer effects in word reading (Nelson, Liu, Fiez, & Perfetti, 2009) predicts that the English reading procedures of the two groups will differ, with CE bilinguals biased towards a lexical reading procedure that encourages holistic orthographic coding, and KE bilinguals biased towards a sublexical reading procedure that encourages analytic orthographic coding. To test this prediction, we evaluate the effects of different stimulus conditions on English word recognition across CE versus KE bilinguals. This includes a manipulation of stimulus orientation to disrupt holistic orthographic coding, which we hypothesize should disproportionately affect the word recognition performance of CE versus KE bilinguals.

1.1. Lexical versus sublexical reading procedures across writing systems

Models of word reading differ in details, but generally posit the existence of two broad types of reading procedures that can support word identification. One type comprises lexical procedures that operate at level of the whole word. For instance, in English, a lexical reading procedure may allow words that occur with high frequency to be recognized "on sight," and allow identification of words with idiosyncratic spelling-sound patterns (e.g., *yacht*) (Coltheart, Curtis, Atkins, & Haller, 1993; Marshall & Newcombe, 1973). The second type comprises procedures that operate on units within the word that are defined within the writing system – e.g., letters in alphabets, syllables in syllabaries, characters in Chinese. These smaller units are separately used to retrieve corresponding phonological and semantic knowledge. The retrieved phonological and/or semantic knowledge is then assembled to produce word identification. For instance, in English, a sublexical procedure allows a reader to draw upon knowledge about sub-word spelling patterns in English that map onto sub-word phonological knowledge (e.g., that 'ck' is usually pronounced as/k/). The resulting sub-word phonological knowledge can then be assembled to access the full pronunciation and corresponding meaning of the printed word (Coltheart et al., 1993; Plaut, McClelland, Seidenberg, & Patterson, 1996).

Most comparisons of lexical versus sublexical reading procedures emphasize differences in the mapping of orthographic knowledge onto corresponding phonological and semantic knowledge. Less attention has been given to the coding of orthographic knowledge itself, although these differences in procedures are likely to give rise to differences in orthographic coding. Qualitative or computational descriptions of lexical reading procedures often describe orthographic coding at the level of a whole word (i.e., holistic coding). Examples of holistic orthographic coding include the use of word shape information (Pelli & Tillman, 2007; Perea & Rosa, 2002), the hierarchical organization of visual feature information that culminates in word-specific orthographic units (Dehaene, 2009), and the distributed representation of visual word forms as unique patterns of activity (Harm, McCandliss, & Seidenberg, 2003). Once the holistic form of the word has been coded, it can be related to the phonology and/or meaning of the given word (Coltheart et al., 1993; Morton, 1969).

Sublexical reading procedures typically rely on orthographic coding at the sub-word levels (i.e., part-based or analytic coding). Examples of part-based orthographic coding include coding at various grain sizes within an alphabetic system (e.g., letters, consonant clusters, orthographic rime units), coding of radicals within the Chinese writing system, and coding of akshara within the Indic alphasyllabaries. Part-based coding may operate sequentially, as in classic models of assembled phonological access (Coltheart et al., 1993), or in parallel, as in connectionist models of orthographic-phonological mapping (Seidenberg, 2005). As the orthographic parts are coded, they retrieve corresponding units of phonology and/or semantics that are quickly integrated to achieve word recognition.

An implication of these observations is that highly practiced individual reading procedures may produce a preference for one or the other orthographic coding choices. Lexical-level procedures create a preference for holistic coding and sublexical procedures create a preference for analytic coding. These individual reading procedures are shaped by two sources. One is familiarity. When a specific word form is encountered with sufficient frequency, lexical level procedures come to dominate for that word and holistic orthographic coding, specific for that word, becomes routine (Coltheart et al., 1993; Plaut et al., 1996; Share, 1995; Wong et al., 2011). Beyond individual words, a second influence on reading procedures comes from the writing system. The influence of the writing system is more pervasive, because it can shape a bias for lexical procedures and holistic orthographic coding or one for sublexical procedures and analytic orthographic coding (Bhide, 2015).

Alphabetic writing and the morpho-syllabic writing of Chinese contrast clearly in their potential for shaping reading procedure biases. English and Korean Hangul are examples of alphabetic orthographies, which map graphemes (letter or letter clusters) to minimal and meaningless speech units (phonemes), although the two scripts have a different visual organization. English arranges letters in a linear sequence, whereas Hangul arranges letters in square-like patterns that correspond to syllables (for a representative comparison, see Fig. 1, Wang, Koda, & Perfetti, 2003). Alphabetic writing systems are well suited for sublexical reading procedures. Beginning readers can use early knowledge about letter-sound correspondences to "decode" the pronunciation of an unfamiliar printed word and thereby bootstrap their own reading development (Share, 1995). For this reason, reading instruction in both English and Hangul (Cho & McBride-Chang, 2005; Eunice Kenney Shriver National Institute of Child Health and Human Development, 2010; Wang, Cho, & Li, 2017) typically includes explicit teaching and practicing of letter-sound correspondences. Further, measures of phoneme-level awareness predict the emergence of L1 reading skill in both English and Korean (Cho & McBride-Chang, 2005; Jung, Pae, & Kim, 2006; Verhoeven & Perfetti, 2017; Wang et al., 2017) children. Once orthographic knowledge has formed from reading experience (Share, 1995), skilled readers can deploy lexical and sublexical procedures in parallel, thereby increasing the speed of word recognition for infrequently encountered words (Coltheart et al., 1993).

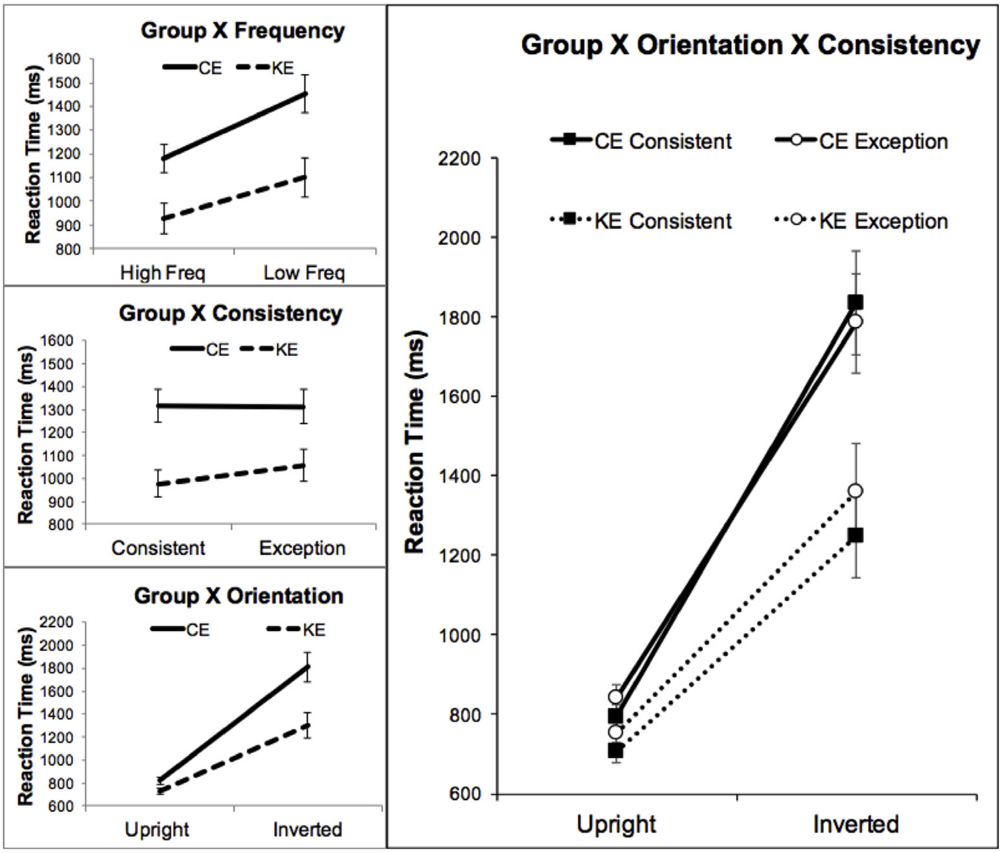

Fig. 1. Significant interactions between Group and stimulus factors (Frequency, Consistency, Orientation) on word naming reaction time (RT). Several two-way interactions involving Group and a stimulus factor were observed. CE as compared to KE participants showed an increased sensitivity to Frequency (slower naming of low versus high frequency words) and Orientation (slower naming of inverted versus upright words). In contrast, CE were less sensitive to the effects of consistency (slower naming of inconsistent versus consistent items), especially when words were presented in an inverted orientation, revealed by the three-way Group X Orientation X Consistency interaction.

Chinese, a morpho-syllabic writing system, presents a different case, with words composed of one or more characters, which in turn are composed of one or more radicals. The structure of a character discourages an analytic approach, because while a radical can provide a cue to pronunciation or meaning, it does so unreliably (Perfetti, Liu, & Tan, 2005). A growing base of evidence suggests that Chinese characters, the majority of which can stand alone as words or be combined as morphemes in multi-character words, are analyzed holistically. One source of evidence comes from the use of "complete composite" paradigms. In this paradigm, participants compare the parts of two characters (e.g., the top halves) while being instructed to ignore the other parts. In congruent trials, both the attended and unattended parts are identical or mismatching. In incongruent trials, the attended and unattended parts are different. Poorer performance in the incongruent condition, especially when the parts of the characters are visually aligned, suggests the form of the entire character influences its perception. Such obligatory processing is a hallmark of holistic visual perception (Gauthier & Bukach, 2007). Using this approach, holistic word effects have been reported (Chen, Abbasi, Song, Chen, & Li, 2016; Wong et al., 2012), although they may be obscured if performance is at ceiling (Hsiao & Cottrell, 2009). Another approach has been to investigate the effects of stimulus inversion, which is thought to disrupt holistic visual perception (Farah, Tanaka, & Drain, 1995). Inversion of Chinese characters increases the time to make matching decisions about their perceptual forms (Luo, Chen, & Zhang, 2017; Wang, Kuo, & Cheng, 2011), slows an electroencephalographic signature of orthographic processing (Wang et al., 2011), and reduces the hemodynamic response to the printed word forms (Kao, Chen, & Chen, 2010). A third approach has been to compare the neural habituation to repeating the same character, as compared to a non-identical character with a shared component radical. Across a wide swath of visual association cortex, Mo, Yu, Seger, and Mo (2015) found that only the identical condition produced a significant repetition effect, suggesting that the orthographic forms for Chinese characters are coded as mutually distinctive wholes. In sum, a growing base of evidence suggests that holistic orthographic coding plays in important role in Chinese reading.

This is not to exclude a role for analytic orthographic coding in Chinese. Luo et al. (2017) found stronger inversion effects for characters with the most common (left-right) radical structure, suggesting that Chinese orthographic analysis is sensitive to the statistics of how character components (i.e., radicals, strokes) are configured. Relatedly, Liu, Chung, McBride-Chang, and Tong (2010) compared the effects of reversing versus randomly recombining the radicals within a character, and the characters within word. When asked to decide whether a presented item was or was not a real character, participants were poorer at rejecting non-characters composed of reversed as compared to randomly reorganized radicals, suggesting that analytic processing of character components (i.e., radicals) occurs. However, when asked to decide whether a presented item was or was not a real word, participants were equally capable of rejecting nonwords composed of reversed as compared to randomly reorganized characters, suggesting that analytic processing of the word components (i.e., character) did not occur. Future work involving perceptual tasks (e.g., complete composite paradigms) could help to establish whether this evidence for holistic processing of multi-character words extends down to the orthographic level. Most important for the present argument, however, is not whether a given orthography involves exclusive use of analytic versus holistic orthographic coding, but rather whether differing reading procedure biases are associated with corresponding biases towards analytic versus holistic orthographic coding.

1.2. Hypothesized L1-L2 transfer of reading procedures

The central question of the present study is whether CE bilinguals transfer a presumed L1 bias for lexical reading procedures to reading in an alphabetic L2. To examine this question, the study compares the English reading profile of CE and KE bilinguals. These two groups have L1 orthographies that are contrastive in terms of mapping principles (morpho-syllabic vs. alphabetic, respectively) but similar in visual-spatial structure (e.g., both orthographies involve the square-like composition of graphs in which spatial position conveys important information). This helps to locate any L1-L2 transfer effects in word reading as due to contrastive reading procedures rather than visual-spatial processing differences. Since both lexical and sublexical reading procedures can support word recognition in alphabetic systems, both Chinese and Korean L1 groups can transfer their L1 biases to English L2 reading. This hypothesis about the L1-L2 transfer of word reading procedures predicts that CE bilinguals will show a bias towards a lexical reading procedure and holistic orthographic coding in their English reading, whereas KE bilinguals will show a bias towards a sublexical reading procedure and analytic orthographic coding.

1.3. Assessing L1-L2 transfer in word reading procedures

Prior studies have provided some evidence for L1-L2 transfer effects in word reading. Haynes and Carr (1990) asked CE bilinguals to make same-different judgments on English letter strings. They found that the CE bilingual group benefited less from the ability to "sound-out" the letter strings than a group of native English speakers. Similarly, with a semantic categorization task, Wang et al. (2003) found evidence for reduced phonological coding and increased reliance upon visual analogy in CE relative to KE bilinguals. These studies support the hypothesis that CE readers have a bias for lexical reading procedures that transfers to an alphabetic L2. However, neither study required subjects to pronounce or simply recognize printed word forms, and thus the results might reflect differences in the task strategies of CE bilinguals, rather than differences in their reading styles.

The present study uses a word naming task as a more direct way to probe for differences in L2 English word recognition. Specifically, the following factors are examined: 1) lexical frequency (how often a word appears in databases of written text), 2) consistency (whether the pronunciation of a word is predictable based upon the spelling of its rime unit), and 3) lexical status (whether the item is a real word or pronounceable nonword). Individuals with a bias towards a holistic reading procedure should have: 1) heightened sensitivity to the frequency effects, because they are widely regarded as a measure of lexical-level influences; 2) reduced sensitivity to the consistency/regularity effects, because they are widely regarded as a measure of sublexical influences on orthographic-phonological mapping, and 3) comparatively poor nonword reading, which is thought to rely heavily upon an analytic reading procedure (for review, see Bhide, 2015).

Similar research questions have been posed in prior studies of L1 transfer effects on L2 English literacy, with similar manipulations of word properties incorporated into the study designs (Akamatsu, 1999, 2002; Hamada & Koda, 2010; Wang & Koda, 2005). The studies do report positive evidence for group effects, with some indications that individuals from non-alphabetic as compared to alphabetic backgrounds show a heightened sensitivity to both frequency and consistency effects. Notably, this is contrary to the predictions we made above, in which opposing effects are expected for manipulations of frequency and consistency. Overall, however, the specific patterns of significant group x stimulus factor interactions are inconsistent across studies (see Table 1). The mixed results suggest that if L1-L2 transfer effects in word reading are present for English literacy, they are not reliably observed under typical conditions. On one hand, this could indicate that transfer effects are small in size or highly variable. On the other hand, it could indicate that transfer effects are masked when the testing conditions permit the routine and skilled use of established reading procedures, since both lexical and sublexical reading procedures can support word recognition in an alphabetic orthography.

1.4. Assessing L1-L2 transfer effects in orthographic coding

As a complementary way to test for L1-L2 transfer of word reading procedures, the present study manipulates the visual display of the stimuli by presenting them in either an upright or inverted (turned upside down, via a 180° rotation) orientation. The purpose of inversion it to disrupt holistic orthographic coding, and thereby the effectiveness of lexically based reading procedures. Three lines of evidence support this reasoning. First, behavioral studies consistently observe an adverse effect of rotation on reading performance. Koriat and Norman (1985) found that when words were rotated beyond a 60° angle, increases in string length resulted in increases in the time to make a lexical decision. The emergence of a word length effect for rotated words has led to proposals that a correction mechanism sequentially rotates pieces (letters or letter clusters) of the word to a standard orientation (Bhide, 2015; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001). Second, neuroimaging results suggest that when word rotation disrupts the parallel processing of letters within a word, parietal brain regions associated with a serial (letter-by-letter) reading process are engaged (Cohen, Dehaene,

Table 1
Results from prior studies contrasting L1 groups on L2 English naming tasks.

	G	G x F	G x R	G x F x R
Accuracy				
Akamatsu (1999)	N.S.	N.S.	** CE + JE < PE, esp. for exception words	** CE + JE < PE, esp. for low frequency exception words
Akamatsu (2002)				
Hamada and Koda (2010)				
Wang and Koda (2005)	*** CE < KE	N.S.	* CE < KE, esp. for exception words	N.S
Reaction time				
Akamatsu (1999)	N.S.	N.S.	N.S.	N.S.
Akamatsu (2002)	** PE & CE slower than JE	* CE especially slow for low frequency words	N.S.	N.S.
Wang & Koda	N.S.	N.S.	N.S.	N.S.
Hamada and Koda (2010)	*** CE slower than KE			

Results from comparisons involving L1 group as a factor across four studies reporting L2 naming of English words (all studies) and nonwords (Wang & Koda, 2005; Hamada & Koda, 2010). Listed results for Akamatsu (1999) are those obtained from an ANOVA model that contrasted an alphabetic L1 group (Persian) to two non-alphabetic L1 groups (Chinese, Japanese), with Frequency, Regularity, and case-alternation as stimulus factors. The table does not include significant effects that involved case (non-alphabetic groups more affected, especially for low frequency items). Results for Akamatsu (2002) are for an ANOVA model that contrasted L1 group (Persian, Chinese, Japanese), with Frequency and Regularity as stimulus factors. Results for Wang and Koda (2005) are from an ANOVA model that contrasted L1 group (Korean, Chinese speakers) with Frequency and Regularity as stimulus factors. The table does not include reported nonword results (poorer accuracy but not slower reaction times for CE as compared to KE). Results from Hamada and Koda (2010) are for an ANOVA model that contrasted L1 group (Korean, Chinese) with Lexicality as a stimulus factor, for reaction time only. G = Group, F = Frequency, R = Regularity, PE = Persian-English, JE = Japanese-English, CE = Chinese-English, KE = Korean-English; ***$p < .001$, **$p < .01$; *$p < .05$. N.S. = $p > .05$. Empty cells indicate conditions for which statistical results are not available.

Vinckier, Jobert, & Montavont, 2008). Third, face processing research has found that inverting a face image, either by flipping or turning it upside down, disrupts face recognition (Farah et al., 1995). This is because the holistic process used to identify upright faces cannot be applied to inverted faces (Maurer, Grand, & Mondloch, 2002; Yovel & Kanwisher, 2008). Instead, inverted faces are recognized through an analytic (or feature/part-based) process that is less efficient, more prone to errors and requires additional time to complete (Kanwisher & Yovel, 2006). This process is reminiscent of the piecemeal correction mechanism used to explain the mental restoration of a rotated word to its normal orientation (Koriat & Norman, 1985) and the serial processing invoked to explain the neuronal signature associated with reading a rotated word (Cohen et al., 2008).

The hypothesis of L1-L2 transfer in word reading procedures predicts larger effects of inversion on the naming performance of CE compared to KE bilinguals. This is because CE bilinguals are predicted to have a bias towards lexical reading procedures, and the associated use of holistic orthographic coding. Therefore, if recovery from inversion involves a piecemeal correction process that produces sublexical orthographic units, CE bilinguals should need to recover sufficient visual information to represent the likely orthographic form of the word before they can gain access to corresponding phonological and semantic content. In contrast, KE bilinguals should be able to take advantage of the piecemeal correction mechanism as it proceeds, because they can readily map between sublexical orthographic and phonological units. Overall, this logic predicts that inversion should disrupt naming speed, especially for CE bilinguals.

1.5. Summary

To summarize, our study tests the hypothesis that reading procedures shaped in a reader's L1 writing system transfer to L2 writing, by comparing bilinguals who have non-alphabetic versus alphabetic L1 orthographies. We predict that CE and KE bilinguals will show differential effects of stimulus type on English word naming, because CE bilinguals should have a stronger L1 bias towards lexical reading procedures than do KE bilinguals and will transfer this bias to L2 English reading. Furthermore, we hypothesize that the ability to name inverted English words will be compromised more for CE bilinguals than KE bilinguals, because the 180° rotation should disproportionately disrupt the use of holistic orthographic coding that is associated with lexical reading procedures. Therefore, inversion sensitivity should reveal L1-L2 transfer effects in word reading that may be otherwise masked by skilled processing.

2. Method

2.1. Participants

Two groups of adults participated in this study: 20 native Chinese speakers with English as the primary second language (CE group), and 18 native Korean speakers with English as the primary second language (KE group). Participants were recruited through ads posted at the University of Pittsburgh campus, and through the dissemination of study information to instructors and students in

English as a Second Language (ESL) courses taught at the University of Pittsburgh and Carnegie Mellon University. Sixteen of the CE bilinguals were from Mainland China and four were from Taiwan. The KE bilinguals were all from South Korea. Participants completed a detailed Language History Questionnaire, which included questions about the age at which they began to learn English as a second language (age of acquisition, AOA), the length of their immersion in an English-speaking environment, self-ratings of English proficiency (e.g., level of reading, writing and speaking abilities), and current use of English (e.g., amount of time spent watching TV, surfing the internet, etc.).

Across the two groups, the participants did not report any history of reading difficulties in their native language or any prior injuries that may have resulted in neurological damage. All of the participants were right-handed, had normal or corrected-to-normal vision and were paid for their time. They all gave written informed consent according to the guidelines established by the Institutional Review Board at the University of Pittsburgh.

2.2. Tests and stimulus materials

2.2.1. Measures of reading skill

The reading skill of participants was assessed with three subtests of the Woodcock Reading Mastery Tests – Revised, Form H (WRMT; Woodcock, 1998). These were Word Identification, in which participants read aloud a list of words, Word Attack, in which participants read aloud a list of nonwords, and Passage Comprehension, in which participants supply missing words that best fit the context of short passages.

2.2.2. Measures of phonological ability

Phonological abilities were assessed with two custom-made tasks (Spoonerism and Phoneme Deletion) and a standardized test (Nonword Repetition). The Spoonerism test (Brunswick, McCrory, Price, Frith, & Frith, 1999) is a challenging phonological awareness task that requires manipulation of phonemes while maintaining items in working memory. Participants listen to pairs of unrelated words (e.g. basket-lemon). After hearing each pair, they are asked to swap the initial sounds in each word and say aloud the resulting nonwords (e.g. lasket-bemon). This task has 12 test items. Additional details are described in Brunswick et al. (1999). The Phoneme Deletion task examines the manipulation of sublexical phonological structure in English through both spoken and written responses (Wang et al., 2003). Participants read aloud a word, then remove a designated sound within the word (indicated within a phonemic bracket/ /), and then say aloud the resulting new word and write it down on an answer sheet. Emphasis is placed on the new word being a real word in English, which should be correctly spelled. This task has 15 test items. The Nonword Repetition subtest from the standardized Comprehensive Test of Phonological Processing (CTOPP; Wagner & Torgesen, 1999) involves listening to a spoken nonword, and then repeating it aloud as accurately as possible. The 18 test items gradually increase in length from one to seven syllables.

2.2.3. Naming task

To assess English word naming ability, participants read aloud sets of printed English words and nonwords, which were presented in either an upright or inverted (turned upside down, via a 180° rotation) orientation. The stimuli were 200 distinct one-syllable words and 50 distinct one-syllable pronounceable nonwords. The word items were selected to be either high or low frequency (respectively, less than 30 and more than 30 counts per million in the Kucera-Francis corpora (Kucera & Francis, 1967), with either consistent or inconsistent spelling-to-sound mappings (based on Plaut et al. (1996). The consistent stimuli also followed the dual-route definition of regularity, meaning that the spelling-sound mappings followed the conventional pronunciation rules of English, whereas the majority (78%) of the inconsistent stimuli were irregular according to this definition. Additionally, the number of “friends” and “enemies” of each word was controlled. A “friend” is a word that shares the same pronunciation of its rime unit with the target word (e.g., COME and SOME). An “enemy” is a word that shares an orthographic rime unit but not its pronunciation with the target word (e.g., COME and HOME). All of the consistent words in our stimulus set have a high degree of consistency, because they have only friends and no enemies (i.e., one possible pronunciation of their rime unit). The inconsistent items have more enemies' than friends, for example the word COME had 2 friends (e.g., SOME) but 6 enemies (e.g., HOME). The nonword items were drawn from previous studies (e.g., Glushko, 1979).

The stimulus items were divided into two lists of 100 words and two lists of 25 nonwords. In each word list, there were 25 items in each stimulus category (high frequency consistent, high frequency inconsistent, low frequency consistent, low frequency inconsistent). The different lists were associated with the upright and inverted display conditions, as detailed in the Procedure section. To dissociate the effect of the display orientation from the effects of stimulus type on performance, we matched the two word lists on written frequency (mean $\pm$ SD for List A: 253 $\pm$ 474, List B: 250 $\pm$ 607, (Kucera & Francis, 1967), consistency of spelling-sound mappings (quantified as the mean number of friends and enemies per item, see (Plaut et al., 1996) (mean $\pm$ SD of 5.2 $\pm$ 5.7 and 5.1 $\pm$ 5.9), number of letters (mean $\pm$ SD of 4.4 $\pm$ 0.8 and 4.4 $\pm$ 0.8) and number of phonemes (mean $\pm$ SD of 3.3 $\pm$ 0.7 and 3.3 $\pm$ 0.8). The two nonword lists were matched on number of letters (mean $\pm$ SD of 4.2 $\pm$ 0.4 and 4.2 $\pm$ 0.5) and phonemes (mean $\pm$ SD of 3.5 $\pm$ 0.5 and 3.5 $\pm$ 0.6); they were also matched to the word lists on these characteristics.

2.3. Procedure

Participants were tested individually in a quiet room. Testing took approximately two hours, including a mandatory 10-min break halfway through the session. The different tasks (and Language History questionnaire) were administered in a predetermined constant order across participants. The assessments of reading skill, phonological ability, and word naming were interleaved to minimize fatigue and boredom. Participants also completed a lexical decision task; this task was part of a development effort for another study and it will not be discussed further.

2.3.1. Reading skill and phonological ability

The WRMT reading skill subtests (Woodcock, 1998), the Spoonerism task (Brunswick et al., 1999), the Phoneme Deletion task (Wang et al., 2003), and the Nonword Repetition subtest (CTOPP; Wagner & Torgesen, 1999) were administered according to the published procedures. For each test, the experimenter gave detailed instructions and practice items, if applicable. All of the participants understood the instructions and completed the practice items successfully.

2.3.2. Naming task

The naming task was administered using a Dell Dimension DIM4700 computer with a 17-inch screen. The stimuli were displayed using E-Prime software (Version 1.1, Psychology Software Tools, Inc., Pittsburgh, PA). The participants viewed the stimuli from a distance of approximately 50 cm. A voice key incorporated into a serial response box (Model 200A, Psychology Software Tools) recorded the time it took the participant to overtly pronounce each item from the moment it appeared on the screen (i.e., RT); accuracy was coded offline from a recording of the participant's overt responses.

In the naming task, participants read aloud words and nonwords that were presented in either an upright or an inverted (180° rotated) orientation. The stimuli were 3–6 letters long and appeared in Comic Sans font at the center of the screen, in black lowercase letters against a white background. The items extended about 10 mm vertically and on average 30 mm horizontally.

The orientation of the displayed items and their lexical status was blocked; therefore, each item list was associated with either the upright or the inverted condition. Across participants, the order of the display condition was counterbalanced, such that half of the participants began with the upright orientation and the other half began with the inverted orientation. We chose to block the display type to avoid task switching confounds. Within each display condition, the block of word items always appeared before the block of nonword items. This was done out of concern that initial exposure to nonwords could prime the use of an analytic reading strategy in all participants.

Each block began with a cue indicating the orientation of the displayed items (“STANDARD DISPLAY”, “INVERTED DISPLAY”). Within each block, the trial began with a 500 ms black fixation-cross followed by the stimulus, which appeared at the center of the screen and remained there until the participants responded. Following the overt response, the item was replaced by a fixation cross that cued participants to press a button when they were ready for the next trial. Within each block items appeared in random order, without replacement. Participants were instructed to read the items presented aloud as quickly as they could without making any errors. Each participant completed 6 practice trials before data collection commenced: 3 upright and 3 inverted items (2 words and 1 nonword per display condition).

2.4. Data analysis

2.4.1. Reading skill and phonological ability

The WRMT offers several metrics for reporting test scores. Standard scores are adjusted for age and subtest differences, such that a score of 100 indicates an age-adjusted level of performance that is equivalent to an average native English speaker on the given subtest. W-scores provide an equal-interval measure of test performance and they are the preferred measure for most statistical comparisons of group differences (Woodcock, 1998). We report W-scores in Table 2. The W-scores were used in the statistical tests. Data from the WRMT were analyzed using a multivariate analysis of variance (MANOVA), with L1 group (KE, CE) as the independent variable and subtest W-scores (Word ID, Word Attack, Passage Comprehension) as the dependent variables. An average W-score for the WRMT tasks was also calculated as an estimate for overall reading skill.

Each phonological ability task yielded an accuracy score as a performance measure. Following Brunswick et al. (1999), accuracy on the Spoonerism task was scored as the number of item pairs produced correctly – both the complete pronunciation of each word and in the correct order – out of a possible 12 items. The Phoneme Deletion task can be scored by separately coding different types of responses (e.g., fully correct, phonologically or orthographically incorrect; both phonologically and orthographically incorrect) (Wang et al., 2003). However, as we have done in past work (Perfetti, Landi, & Oakhill, 2005), we adopted a simpler binary coding

Table 2
Demographics and English proficiency and use for CE and KE groups.

	Chinese		Korean				
	Mean	SD	Mean	SD	*t*	*p*	*d*
Age	28	5.1	28.2	4.7	0.1	0.92	0.03
Years of Education	17.8	2.4	17.8	2.3	0.07	0.95	0.02
Age of Acquisition	12.6	1.8	12.1	2.6	0.68	0.5	0.23
TOEFL Score	586	32	587	38.6	0.08	0.94	0.04
English Proficiency	23.8	6.9	25.4	6.1	0.75	0.46	0.25
Frequency of Use	22.6	3.2	22.7	2.1	0.07	0.94	0.02

scheme (correct, incorrect), since this provided consistency across our measures and previous results suggest it is sufficient to observe L1-L2 transfer effects (Wang et al., 2003). Therefore, accuracy on the Phoneme Deletion task was scored as scored as the number of items that were both written and pronounced completely correctly, out of a possible 19 items. Accuracy on the Nonword Repetition subtest was scored using standard instructions, and reflects the number of items that were pronounced completely correctly, out of a possible 18 items. The accuracy scores from these phonological tasks were converted to accuracy rates, and analyzed using a MANOVA, with L1 group (KE, CE) as the independent variable and phonological test scores (accuracy rate on Spoonerism, Phoneme Deletion, and Nonword Repetition) as the dependent variables.

2.4.2. Naming task

The naming task yields a measure of the pronunciation accuracy and onset of pronunciation (reaction time, RT) for each item. RTs that were less than 250 ms resulted from an overt response that was initiated before the word appeared on the screen, and therefore these trials were removed prior to analysis (CE: 0.24% trials, KE: 0.28% trials). RTs were analyzed only for trials in which pronunciation of the stimulus items was correct. Word naming performance (RT, accuracy) was probed using mixed-model analyses of covariance (ANCOVAs). These models included the within-subject stimulus factors of Frequency (high, low), Consistency (consistent, inconsistent), and Orientation (upright, inverted); the between-subjects factor of Group (CE, KE); and Reading Skill (mean W score for each participant across the three administered WRMT subtests) as a covariate. Similarly, nonword naming performance (RT, accuracy) was probed using analyses of covariance (ANCOVAs) with stimulus Orientation (upright, inverted) as a within-subjects factor, Group (CE, KE) as a between-subjects factor, and Reading Skill (mean W score) as a covariate.

3. Results

3.1. Participant profiles, reading skill, and phonological abilities

Demographic and English language and reading skill measures for the study participants are shown in Table 2. The bilingual groups did not differ on their mean age or number of years of education. Ninety-five percent of the CE bilinguals and 78% of the KE bilinguals had a college degree. Responses on the Language History Questionnaire indicated that the bilingual groups did not differ in their self-reported L2 age of acquisition, English proficiency, or current use of English. In addition, 45% of the CE participants and 78% of the KE participants reported their scores on the Test of English as a Foreign Language (TOEFL). The bilingual groups did not significantly differ on their TOEFL scores.

The WRMT standardized score means for both bilingual groups fell within the range of normal English reading ability on all tests, with the exception of the Word Identification score for the CE group (which fell near the cut-off for adult native English readers). Although the two groups were well matched in terms of English language experience and ability, the MANOVA of WRMT W-scores revealed a main effect of L1 group ($F(3,34) = 3.74$, $\eta^2 = .25$, $p = .02$), with higher levels of performance by the KE than the CE participants. Follow-up t-tests revealed that the KE participants had higher scores for Word ID and Word Attack but not Passage Comprehension. KE participants also maintained a significantly higher overall reading skill compared to CE participants (see Table 3). The MANOVA on the phonological tests also revealed a main effect of L1 group ($F(3,34) = 9.36$, $\eta^2 = .45$, $p < .001$). Follow-up t-tests revealed that the KE group had lower scores for Nonword Repetition and higher scores on the Spoonerism test compared to the CE group, but the two groups had similar scores on Phoneme Deletion (see Table 3). These results indicate that, in general, the CE and KE participants were skilled L2 readers of English, but the two groups exhibited different profiles of L2 English reading and phonological ability.

3.2. Naming task

RT and accuracy data from the Naming Task were analyzed using mixed-model ANCOVAs, separately examining the results for words and nonwords. For words, the models included Frequency, Consistency, and Orientation as within-subject factors, Group as a between-subjects factor, and Reading Skill as a covariate. For nonwords, the models included Orientation as a within-subjects factor, Group as a between-subjects factor, and Reading Skill (average WRMT W-score) as a covariate. The significant results are detailed in

Table 3
Reading and phonological skills of the CE and KE groups.

Task	Mean		SD		*t*	*p*	Cohen's *d*
WRMT Reading Skill Task	CE	KE	CE	KE			
Word ID	520	531	12.0	9.35	3.14	0.003	1.03
Word Attack	505	511	7.83	9.19	2.05	0.048	0.66
Passage Comprehension	516	519	12.4	12.8	0.77	0.45	0.25
Average Reading Skill	514	520	9.57	8.87	2.20	0.034	0.72
Oral Phonological Tasks							
Spoonerism	5.85	8.11	2.56	2.56	2.72	0.01	0.88
Nonword Repetition	13.50	10.83	2.14	2.85	3.28	0.002	1.06
Phoneme Deletion	12.15	11.67	1.95	3.14	0.58	0.57	0.18

Table 4
Significant effects on reaction time data for word and nonword reading.

	Word Reading Reaction Time		
Main Effects	*F*	*p*	η^2
Group	8.84	0.005	0.20
Interactions			
Frequency X Group	4.62	0.039	0.12
Consistency X Group	5.17	0.029	0.13
Orientation X Group	8.85	0.005	0.20
Consistency X Orientation X Group	5.09	0.03	0.13
all other *ps* > .18			
	Nonword Reading Reaction Time		
Main Effects	*F*	*p*	η^2
Group	10.89	0.002	0.24
Interactions			
Orientation X Group	9.95	0.003	0.22

all other *ps* > .32.

Table 4.

In the analysis of word naming RTs, a significant main effect of Group, and significant interactions between Group x Frequency, Group x Consistency, Group x Orientation, and Group x Consistency x Orientation were observed (see Table 4). As shown in Fig. 1, these results reflect the fact that CE as compared to KE participants showed an increased sensitivity to frequency (slower naming of low versus high frequency words) and inversion (slower naming of inverted versus upright words). In contrast, they were less sensitive to the effects of consistency (slower naming of inconsistent versus consistent items), especially when words were presented in an inverted orientation. For nonword naming RTs, a significant main effect of Group, and a significant interaction between Group x Orientation was observed. As with words, CE participants were more slowed, as compared to KE participants, by the presentation of stimuli in an inverted versus upright configuration.

In the analysis of accuracy, significant main effects of Frequency, Reading Skill, and a Frequency x Reading Skill interaction were observed (Table 5), with poorer word naming accuracy for low frequency items, especially for participants with poorer reading skill. Further, a significant main effect of Group was observed, with poorer performance of CE as compared to KE bilinguals (estimated marginal means of 0.82 (SD = 0.07) and 0.89 (SD = 0.04), respectively). Additionally, marginal Group x Frequency, Orientation, and Orientation x Reading skill interactions were observed. For nonword naming accuracy, no significant effects were observed. However, the effect of Group was in a similar direction to that observed for word naming accuracy (estimated marginal means for CE and KE bilinguals of 0.77 (SD = 0.13) and 0.83 (SD = .08), respectively), and the effect of Reading Skill was marginally significant. These results are consistent with the WRMT results, where group differences were more pronounced for the Word ID as compared to the Word Attack subtest.

4. General discussion

The results support the hypothesized effect of L1 literacy experiences on L2 English reading. KE and CE participant groups, whose written first languages follow different design principles for mapping orthography onto phonology and semantics, showed different adaptations to reading alphabetic English with inverted print. These differences imply that KE readers use sublexical reading procedures and analytic orthographic coding in reading English, whereas CE readers use lexical procedures and holistic coding to read

Table 5
Significant effects on accuracy data for word and nonword reading.

	Word Reading Accuracy		
Main Effects	*F*	*p*	η^2
Group	6.67	0.014	0.16
Reading Skill	19.79	< .001	0.35
Frequency	10.55	0.003	0.23
Interactions			
Frequency X Reading Skill	8.82	0.005	0.20
Marginal Effects			
Orientation	3.25	0.080	0.085
Frequency X Group	3.10	0.087	0.081
Orientation X Reading Skill	2.90	0.098	0.076
all other *ps* > .21			
	Nonword Reading Accuracy		
Marginal Effects	*F*	*p*	η^2
Reading Skill	3.21	0.082	0.084

all other *ps* > .23.

English. We review below the evidence for these conclusions.

4.1. L1-L2 transfer effects on the speed of word identification

The strongest evidence in support of L1-L2 transfer effects on reading procedures comes from the naming task RT data. Given evidence that stimulus inversion disrupts holistic visual analysis (Maurer et al., 2002) we reasoned that it should particularly disrupt the naming performance of CE versus KE participants. Results support this: CE bilinguals were more affected by the inversion manipulation than KE bilinguals.

Pae and colleagues have proposed a related set of ideas and conclusions (Pae & Lee, 2015; Pae, Kim, Mano, & Kwon, 2017). In this work, the authors similarly reasoned that CE bilinguals transfer a bias towards lexical processing to L2 English reading, whereas KE bilinguals transfer a bias towards sublexical processing. Further, they similarly reasoned that different kinds of visual noise should differentially impact lexical versus sublexical reading procedures, and therefore visual manipulation of printed words can reveal L1-L2 transfer effects on word reading. More specifically, they hypothesized that alternating and inverting fonts (similar to the current study) should disproportionately disrupt lexical processing, and found that CE bilinguals were more affected than KE bilinguals (Pae & Lee, 2015). In contrast, they hypothesized that scrambling internal letters (e.g., river → rvier) should disproportionately disrupt sublexical processing, and found that KE bilinguals were more affected than CE bilinguals (Pae et al., 2017). In sum, like the current study, the results of Pae and collaborators strongly support a connection between orthographic coding and reading procedures. Further, they highlight how visual distortions (such as inversion) can unmask individual differences (such as differing L1-L2 biases), which might otherwise be hard to detect if the stimulus conditions permit the skilled use of acquired reading procedures and orthographic coding.

In addition to manipulating the visual properties of the stimuli, the current study manipulated two psycholinguistic factors (frequency and consistency). The observed interactions between these factors and bilingual group provide further support for the L1-L2 transfer of reading procedures, as well as the presumed link between reading procedures and orthographic coding. Specifically, the naming times of CE participants were more affected by frequency, a behavioral marker of lexical reading procedures (Bhide, 2015). In contrast, KE participants were more affected by consistency, a marker of sublexical reading procedures (Bhide, 2015), and this was especially the case when the stimuli were presented in an inversion orientation. This is the expected result, because the piecemeal recovery process should yield sublexical orthographic chunks, which KE bilinguals can use to initiate decoding more readily than CE bilinguals. However, this should be accompanied by an increase in phonological interference or confusion for items that have inconsistent spelling-to-sound mappings. Thus, the predicted patterns of L1-L2 transfer effects on word reading were observed, both in terms of inversion effects that disrupt holistic processing and psycholinguistic effects that measure lexical and sublexical processing.

4.2. L1-L2 effects on word identification accuracy

The largest effects in this study were driven by the inversion manipulation, consistent with the idea that inversion can unmask differences in normal reading procedures that are not readily apparent under conditions of skilled reading. Notably, only marginal effects of inversion were observed in accuracy. This suggests that even though CE bilinguals rely upon a less efficient strategy than KE bilinguals to recover from inversion, ultimately it is nearly as successful.

While inversion did not substantially impact the accuracy of word identification, significant effects were observed for L1 group (poorer accuracy for CE vs. KE bilinguals) and frequency (poorer accuracy for low vs. high frequency words), and a marginal interaction was observed between these two factors. A co-varying composite measure of reading skill (from a standardized reading assessment) was also found to predict poorer naming performance, especially for low frequency words. On the surface, the effects associated with the composite measure of reading skill are unremarkable, because there is a large literature demonstrating that familiar words are recognized more accurately than unfamiliar words, and accurate word recognition is a crucial aspect of skilled reading. But the overall pattern of effects is quite intriguing, because the composite reading skill measure was significantly poorer for the CE as compared to KE group. Yet even after this difference was incorporated into the statistical model, an additional effect of L1 group was still observed. Thus, as a group the CE bilinguals entered into the study with a poorer level of reading skill as compared to KE bilinguals, and as a group they additionally exhibited poorer naming performance than expected given their measured reading skill.

Consistent with our findings, several prior studies have reported poorer naming task accuracy for CE bilinguals as compared to those from alphabetic L1 backgrounds (Akamatsu, 1999, 2002; Hamada & Koda, 2010; Wang & Koda, 2005). Importantly, in each of these past studies the CE and alphabetic groups were matched on measures of English language experience and ability, as in the current study. More specifically, the two groups in the current study had nearly identical average age, years of education, age of English acquisition, TOEFL scores, and subjective use of English. Therefore, the observed group difference in word identification skills suggests that CE and KE bilinguals exhibit comparable mastery of spoken, but not written, English.

4.3. Implications of L1-L2 transfer effects for reading development

To account for the observed group differences, we conclude that L1-specific transfer may slow the pace of reading in an L2 with a highly contrastive writing system. The fact that we find group differences while controlling for individual reading skill demonstrates that this effect is not a result of poorly matched groups, but rather a function of their different reading procedures. Consequently, Chinese readers of English may need more time to reach the same English skill level as their Korean counterparts with the same amount of experience. In fact, such group differences are to be expected if CE participants are biased towards a holistic reading procedure.

To understand why this is the case, consider that naming errors in English are most likely to occur when a reader has low familiarity with the printed word form, which increases reliance on decoding procedures to attain phonological access (Plaut et al., 1996; Share, 1995). Even though English has only quasi-regular spelling-to-sound patterns, the degree of consistency is still very high for consonants and for within-syllable onset and rime units (Plaut et al., 1996; Share, 1995). For this reason, the use of sublexical decoding procedures is advantageous, even for unfamiliar words with inconsistent spelling-sound patterns (Share, 1995). This should place individuals with a bias toward lexical reading procedures, such as those from a Chinese L1 background, at a decoding disadvantage and therefore at increased risk for pronunciation errors (Harm et al., 2003).

An individual's history of reading instruction may also exert an influence on the transfer of L1-L2 reading procedures and L2 decoding abilities. In alphabets, orthographic knowledge is typically acquired and reinforced in the context of instruction that emphasizes orthographic to phonological correspondences. In Chinese, phonological decoding is of limited value, and instead instruction typically emphasizes the visual-motor memorization of word forms and their corresponding meaning. As a result, Chinese reading acquisition may enhance an individual's visual-spatial skills (and transfer to reading graphs of other, nonnative writing systems (Chang & Perfetti, in press). This transfer of visual skill may support lexical reading procedures in alphabetic writing and partly compensate for the reduced ability to use sublexical statistics that are characteristic of alphabetic systems. If so, group differences in the fluency and accuracy of word recognition may not be observed for familiar words, which can be identified through lexical procedures. In contrast, group differences should tend to emerge for unfamiliar words or distorted words because word recognition is more reliant on fine-grained orthographic units, where experience with an alphabet could provide a leg up.

Taking this line of reasoning one step further provides the theoretical basis for a causal link to reading development. This is because orthographic knowledge accrues each time an unfamiliar printed word is successfully recoded into its corresponding phonological form (Chalmers & Burt, 2008; Share, 1999; de Jong & Share, 2007). Extending these ideas to the current study, the poorer naming accuracy of CE bilinguals suggests that their phonological recoding is less accurate, and consequently they require more reading experience to achieve the same level of orthographic learning. This “developmental delay” may appear as a lower reading skill, especially as assessed with tests that heavily weight decoding and word identification abilities.

We emphasize, however, that reading skill is multi-faceted. In this study, we found that the CE bilinguals were significantly poorer on measures of English word identification and decoding. Their phonological awareness comparability was less clear. The phoneme deletion task, a standard assessment of phoneme awareness, showed little difference. The Spoonerism task, which showed higher performance by the KE group, is a more complex task goes well beyond awareness of phonemes. The results from the nonword repetition results, where the CE group somewhat surprisingly outperformed the KE group, suggests they do not have a core problem with English phonological representation (Moore, Fiez, & Tompkins, 2017; Ramus, Marshall, Rosen, & van der Lely, 2013). Overall, the profile of results suggest the CE group has subtle difficulty with aspects of English phonological analysis at the sublexical level, consistent with a bias towards lexical reading procedures that do not help to build this skill through reading practice. Importantly, however, the CE bilinguals performed as well as KE bilinguals on a measure of passage comprehension. This indicates that CE bilinguals can achieve a high level of English reading success, despite comparatively poorer performance on word identification and phonological decoding tests that predict reading achievement in native English readers (Koda, 1999). In sum, while CE bilinguals have a distinctive skill profile, they should not necessarily be regarded as poorer readers of English than KE bilinguals.

4.4. Summary

We conclude that differences in L1 background can bias individuals towards the use of lexical versus sublexical reading procedures, and associated differences in holistic versus analytic orthographic coding. Both types of procedures can support English word identification and phonological decoding, albeit with differing levels of success. This may explain why weak and inconsistent L1-L2 transfer effects have been observed by examining the English naming performance of CE and KE bilinguals under typical stimulus presentation conditions. However, by using word inversion to disrupt skilled reading and favor analytic procedures, highly significant effects of L1 background can be observed. The results provide strong support for L1-L2 transfer effects in word reading predicted by an assimilation hypothesis.

More generally, the results provide support for three conclusions that likely apply to both L1 and L2 reading. First, they demonstrate that stimulus inversion can be a powerful tool for unmasking individual differences in reading style. Second, they provide evidence for a link between reading procedure and orthographic coding biases. Third, they provide evidence that both lexical and sublexical reading procedures can be used to attain a high level of English reading skill, though the pace of reading development and the ability to generalize orthographic knowledge will likely be poorer for readers biased towards lexical reading procedures.

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