THE ROLE OF ORTHOGRAPHY TO PHONOLOGY MAPPING IN
BILINGUAL WORD READING: AN ELECTROPHYSIOLOGICAL
INVESTIGATION

A Dissertation in
Communication Sciences and Disorders
by
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Abstract

English monolinguals and highly proficient L1-dominant Spanish-English, Chinese-English and Dutch-English bilinguals made rhyme judgments of semantically unrelated English word pairs presented sequentially in the visual modality, while behavioral and EEG measures were recorded. The spelling-sound consistency and orthographic similarity of rhyming and non-rhyming prime-target word pairs were varied systematically. To manipulate consistency, graphemically dissimilar primes and targets that either matched or did not match in consistency were compared in both the rhyming (consistent/consistent: WHITE-FIGHT versus inconsistent/consistent: HEIGHT-FIGHT) and non-rhyming conditions (consistent/inconsistent: CHURCH-COUGH versus inconsistent/inconsistent: CHILD-COUGH). To manipulate orthographic similarity, primes and targets that were matched on spelling-sound consistency, but varied in the degree of graphemic similarity were compared in both rhyming (orthographically similar: RIGHT-FIGHT versus orthographically dissimilar: WHITE-FIGHT) and non-rhyming conditions (orthographically similar: DOUGH-COUGH versus orthographically dissimilar: CHILD-COUGH). All participant groups were facilitated in responding to rhyming relative to non-rhyming conditions. In processing consistency, all participant groups were facilitated by consistency congruent (WHITE-FIGHT) relative to incongruent (HEIGHT-FIGHT) prime-target pairs in making rhyming decisions. In making non-rhyming decisions, English monolinguals were facilitated by consistency congruent (CHILD-COUGH) relative to incongruent (CHURCH-COUGH) conditions, whereas Spanish-English and Chinese-English bilinguals showed the opposite direction of the effect and Dutch-English bilinguals did not show an effect. In processing
orthographic similarity, all participant groups were facilitated by convergent orthographic and phonological cues (*RIGHT-FIGHT*) in making rhyme decisions, but inhibited by divergent orthographic and phonological cues (*DOUGH-COUGH*) in making non-rhyme decisions. A second group of highly proficient L1-dominant Dutch-English bilinguals made rhyme judgments of semantically unrelated Dutch-English word pairs presented sequentially in the visual modality, while behavioral and EEG measures were recorded. The spelling-sound consistency of the English targets was varied systematically within both rhyming (consistent target: *KREET* [k्रইt] – *TRAIT* versus inconsistent target: *KREET* [kɾeɪt] – *WEIGHT*) and non-rhyming conditions (consistent target: *KREET* [kɾeɪt] – *DARK* versus inconsistent target: *KREET* [kɾeɪt] – *TEAR*). Dutch-English bilinguals were facilitated in responding to rhyming conditions that contained consistent (*KREET* [kɾeɪt] – *TRAIT*) relative to inconsistent English targets (*KREET* [kɾeɪt] – *WEIGHT*), as well as in responding to non-rhyming conditions that contained inconsistent (*KREET* [kɾeɪt] – *TEAR*) relative to consistent English targets (*KREET* [kɾeɪt] – *DARK*). Across the five experiments reported in this dissertation, the results suggested that bilinguals’ transfer of spelling-sound consistency expectations from the L1 to the L2 was modulated by the orthographic distance between the L1 and L2. More specifically, bilinguals whose L1 and L2 orthographies shared the same alphabetic script were more likely to transfer reading strategies from the L1 to the L2, regardless of language immersion and task-specific context, relative to bilinguals whose L1 and L2 orthographies used different scripts. Nonetheless, bilinguals whose L1 and L2 used different scripts judged the degree of English (L2) spelling-sound consistency in comparison with the degree of consistency encountered in their L1.
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Nihil sine Deo.
Dedication

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THE ROLE OF ORTHOGRAPHY TO PHONOLOGY MAPPING IN BILINGUAL

WORD READING: AN ELECTROPHYSIOLOGICAL INVESTIGATION
Chapter 1

Introduction

Skilled reading represents a highly complex and critical ability in the modern world, with far-reaching effects that extend from academic success to overall well-being and life satisfaction (Alexander, 1996). Skilled readers are able to process written text at a fast rate. To achieve this level of fluency, readers must first gain experience in recognizing and identifying visually presented words quickly and accurately. There is a debate surrounding the visual word recognition process experienced by monolinguals. Proponents of the Dual Route model of reading (e.g., Coltheart, Curtis, Atkins & Haller, 1993; Coltheart, Rastle, Perry, Langdon & Ziegler, 2001) argue that visual word recognition involves readers’ ability to retrieve the phonological representation of a known word from the lexicon as a whole unit (whole word approach), or to map a (un)known letter sequence onto phonological representation following explicit knowledge of spelling-sound conversion rules (decoding approach). In contrast, proponents of the Connectionist model of reading (e.g., Seidenberg & McClelland, 1989) suggest that visual word recognition relies upon readers’ implicit learning of letter patterns that follow certain spelling-sound mapping rules and those where exceptions apply. Compelling experimental evidence supports both views (e.g., Balota & Ferraro, 1993; Baron & Strawson, 1976; Chateau & Jared, 2003; Gough & Cosky, 1977; Jared, 1997; 2002; Jared, McRae, & Seidenberg, 1990; Stanovich & Bauer, 1978), suggesting that readers are sensitive to input regularities and adapt their reading strategy in response to experience.
Reading in a second language (L2) adds a level of complexity to the process typically experienced by monolinguals for two main reasons. First, word recognition is believed to be language-nonselective (e.g., Dijkstra & Van Hell, 2003; Dijkstra & Van Heuven, 2002; Midgley, Holcomb, Van Heuven, & Grainger, 2008, but see Costa, 2005, and Roelofs, 1998 for language selective accounts of lexical access), suggesting that bilinguals co-activate the phonology of their first language (L1) when reading in the L2 (e.g., Schwartz, Kroll, & Diaz, 2007). Secondly, languages differ in orthographic depth, known as the degree of arbitrariness of spelling-to-sound mappings. Readers adopt different reading unit sizes (i.e., syllable, rime, whole word) in response to the orthographic depth of their L1 (e.g., Ziegler & Goswami, 2005). Consequently, bilinguals experience the co-activation of L1 reading unit size when reading in the L2. This co-activation is the precursor of cross-linguistic transfer of reading strategies from the L1 to the L2. When bilinguals transfer word-reading skills between two languages with transparent orthographies, they may experience facilitation because the same reading strategy can be used in the L2 even though the specific mappings may differ across languages (e.g., Akamatsu, 1999; Koda, 1989, 1999, Muljani, Koda, & Moates, 1998). However, when bilinguals transfer word-reading skills between languages with distinct degrees of letter-sound mapping transparency, they may experience interference (e.g., Nosarti, Mechelli, Green, & Price, 2009; Wade-Woolley, 1999; Wade-Woolley & Geva, 2000). It is unclear how bilinguals resolve the competition from L1 reading strategy during L2 word reading when the specific spelling-sound mappings (mostly the vowels), as well as the preferred reading unit size differ to a certain extent.
The current work evaluated how differences in orthographic depth between a bilingual’s first and second languages impact reading in the second language. The investigation had three main goals, as follows:

1. To evaluate English monolinguals’ sensitivity to the consistency of English spelling-sound mappings (i.e., the predictability of word pronunciations based on their spelling).
2. To investigate if and how reading unit preferences transfer in bilinguals who read a non-transparent L2 (i.e., English) that differs in the consistency of the orthography-phonology mappings from their L1 (alphabetic and transparent: Spanish; logographic and non-transparent: Chinese).  
3. To test whether the overt co-activation of L1 (i.e., Dutch) reading strategies impacts the reading strategy adopted in the L2 (i.e., English) more than the covert co-activation bilinguals typically experience in L2-only contexts when the L1 orthography is transparent and the L2 orthography is relatively non-transparent.

The goals summarized above will be elaborated in detail in the following sections.

The current research evaluated both behavioral and electrophysiological data (event-related potentials, or ERPs) to better understand the consequences of reading unit size transfer and the series of processes underlying this activation. Past studies of cross-language transfer effects in reading have relied primarily on behavioral methods, but ERPs may reveal implicit processes that may not be evident in the behavioral data alone. The results contribute to the resolution of current debates about the degree to which L2 readers transfer word reading strategies cross-linguistically. Furthermore, the study
provides critical implications for adapting current models of single word reading to the bilingual lexicon.

The dissertation is structured as follows: Chapter 2 explains the theoretical framework that is at the basis of the current research. It provides an overview of visual word recognition, with an emphasis on word reading models developed based on monolingual readers’ performance on word naming and lexical decision tasks. The impact of spelling-sound consistency on word naming performance in monolinguals, and its potential influence on bilinguals’ L2 word reading strategies is highlighted. Furthermore, the chapter discusses the role of orthographic depth in modulating monolinguals and bilinguals’ reading strategies across alphabetic and logographic scripts. A review of word reading strategy transfer between alphabetic orthographies with distinct levels of transparency and across alphabetic and logographic writing systems is also provided. The Event Related Potential technique is subsequently addressed, providing a general review of the ERP components associated with visual word recognition, with a particular emphasis on the ERP indices of phonological processing that will be the focus of the studies included in this investigation. The chapter concludes by providing a detailed explanation of the three studies included in this dissertation and a set of predictions reflecting the reviewed literature. Chapter 3 presents the general method employed by the current studies. Certain aspects of the method will be described in more detail in the subsequent chapters, as needed. Study 1, which investigates English monolinguals’ sensitivity to English spelling-sound mapping consistency, is presented in Chapter 4. Study 2, which evaluates the role of L1 orthographic depth in modulating bilinguals’ choice of reading strategies in a relatively non-transparent L2 orthography
(i.e., English), is presented in Chapter 5. Two sets of non-native English speakers were tested in Study 2: Spanish-English and Chinese-English bilinguals. The two groups were chosen because of the contrast in the relative transparency of their L1 orthography-to-phonology mappings. Spanish-English bilinguals have a transparent L1 alphabetic orthography, whereas Chinese-English bilinguals have a non-transparent L1 writing system (logography). Study 3, which tests bilinguals’ choice of reading units in the L2 (i.e., English) when the L1 is either overtly or covertly co-activated, is presented in Chapter 6. Two groups of Dutch-English bilinguals were tested in the Netherlands for Study 3. One group of Dutch-English bilinguals was tested on a Dutch-English task (overt condition), whereas the other group of Dutch-English bilinguals was tested on an English task (covert condition). Finally, Chapter 7 integrates the present findings with past research and discusses the limitations of the current investigation and future directions.
Chapter 2

Visual Word Recognition

Visual word recognition involves the activation of phonological (pronunciation) and semantic (meaning) information from orthographic representations (visual form). This process requires the ability to visually identify sequences of written symbols (e.g., letters, characters), map them onto the appropriate phonological representations based on a set of constraints, and activate the corresponding semantic representations when available. This basic architecture of the visual word recognition system has generated much research interest over the past decades, as it enabled researchers to understand how literate adults accomplish skilled word reading.

Models of Visual Word Recognition

Research on reading has investigated word naming in an attempt to learn about the system involved in mapping orthography to phonology. Studies have employed monolingual skilled and unskilled readers to perform word-naming tasks in order to identify the process through which visually presented monosyllabic words are read aloud out of context. Based on such studies, two main theoretical approaches have been formed to describe the processes underlying spelling-sound mapping: the Dual Route and Connectionist models of reading. Both models account for much of the same processes, but using different mechanisms of representation, processing and learning.

The Dual Route Model

The dual-route approach to reading achieved popularity in the 1970s, when researchers used words and nonwords to contrast between direct lexical access and grapheme-phoneme mappings as separate routes in the word naming mechanism (e.g.
Baron & Strawson, 1976; Forster & Chambers, 1973; Frederiksen & Kroll, 1976; Marshall & Newcombe, 1973). The Dual Route (DR) model of reading, formally established by Coltheart (1978) and later extended to the Dual Route Cascaded (DRC) model (Coltheart et al., 1993; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001), represents words locally, as lexical entries, and postulates that word reading is mediated by two processes (see Figure 1): (1) a phonological or assembly route in which words are processed serially, one letter at a time from left to right based on explicit grapheme-phoneme correspondence (GPC) rules used to mediate mapping between orthography and phonology; and (2) a lexical or whole-word route, in which phonological codes are retrieved from lexical storage as whole units (Coltheart, 1978; Coltheart et al., 1993; Coltheart et al., 2001). While some researchers argue that the two routes are in competition, the response being determined solely by the first process to finish the “race” (Frost, 1998; Paap & Noel, 1991), others believe that the two processes join forces to generate a phonological representation that can reliably drive articulation (Monsell, Patterson, Graham, Hughes, & Milroy, 1992). Coltheart and colleagues (2001) disagree with the “horse race” metaphor and argue that the two routes of the DRC model are not fully independent from each other, but may work together to activate phonology.

The assembly route (also referred to as the non-lexical or sub-lexical route) is sensitive to spelling-sound regularity and word length, generating correct pronunciations for regular words and unknown letter strings based on standard GPC rules, yet regularizing the pronunciations of irregular words. In contrast, the lexical route is sensitive to word frequency, generating correct pronunciations for any word that is already in the reader’s lexicon. The non-lexical pathway produces a regularity effect, in
that words with regular spelling-sound mappings are named faster and more accurately than irregular words (e.g., Baron & Strawson, 1976; Coltheart et al., 1993; Coltheart & Rastle, 1994; Gough & Cosky, 1977; Stanovich & Bauer, 1978). The faster and more accurate naming of regular words is possible through the convergence of the output generated by the assembly and lexical routes, leading to one pronunciation, whereas the slower and less accurate naming of irregular words is due to the regularized output of the assembly route, which comes at odds with the correct output stored lexically. The sub-lexical route also produces a word length effect on reading latencies since the more graphemes there are to process, the longer the assembly time (Coltheart et al., 2001; Weekes, 1997). The lexical pathway produces a frequency effect, in that words with higher frequency are activated from the lexicon faster than words with lower frequency (Coltheart et al., 2001). Regularity interacts with frequency such that regularity effects are found in low frequency but not high frequency words. This is because high-frequency words are retrieved from the lexicon before information form the assembly route becomes available, thus being unaffected by spelling-sound regularity (e.g., Seidenberg, Waters, Barnes, & Tanenhaus, 1984). For example, even in their 6th year of reading instruction, English-speaking children have problems reading low and mid-frequency irregular words compared to low and mid-frequency regular words (Hanley, Masterson, Spencer, & Evans, 2004).

Skilled readers of English may be able to strategically adjust the relative contribution of lexical and sub-lexical information in response to the context created by the presentation of exception words and/or nonwords. For example, skilled readers named exception words faster and made fewer regularization errors in a blocked condition (i.e., a
block with only exception words) than when randomly mixed with nonwords, suggesting that they adopted a lexical reading route in the blocked condition, but switched between the lexical and sub-lexical reading routes in the mixed condition, producing a switching cost (Monsell et al., 1992; see also Andrews, 1982; Frederiksen & Kroll, 1976). Zevin and Balota (2000) have further demonstrated that the use of a lexical pathway can be primed by naming 5 low-frequency exception words before a target word, whereas the use of the non-lexical route can be primed by naming 5 nonwords before the target.

Although the DRC model adds to the current understanding of the reading process, it has several limitations. First, although the model is built upon the presumption that the knowledge needed to carry out the reading aloud task is gradually developed over time; it solely describes the processing system that results out of completed learning. Second, the grapheme-phoneme conversion rules specify only how graphemes are pronounced in isolation and not how the pronunciation of a grapheme varies depending on the surrounding letters (Jared, 2002). Third, possibly the biggest limitation of the model is its rigidity in accounting for grain size (i.e., the size of the reading unit). The sub-lexical route relies on the smallest grain size (i.e., individual graphemes), whereas the lexical route uses the largest grain size (i.e., whole word). What is lacking is a grain of medium size that accounts for a reading strategy adopted in response to the statistical learning of regularities and exceptions to the rule. Such mid-size reading unit is made available by the Connectionist model of reading (Seidenberg & McClelland, 1989), which is the model adopted in the current research.
The Connectionist Model

Unlike the Dual Route model, the Connectionist model of reading (Seidenberg & McClelland, 1989) assumes that the process of visual word recognition requires a single procedure (see Figure 2). Simulating a neural network, the model employs different patterns of activation among units representing orthography, phonology and semantics (Seidenberg & McClelland, 1989, 1990). A learning algorithm gradually creates and adjusts the strengths of connections between units (i.e., weights) based on experience (Coltheart, 2006; Seidenberg & McClelland, 1989). This algorithm allows the model to
learn through experience how to accurately compute phonological representations. Consequently, words have distributed representations, their letters being processed simultaneously through spreading activations that make available alternative pronunciations of a given spelling pattern. This network approach to lexical representation makes the lexical route of the dual route model seem redundant. Furthermore, the “hidden units” connecting the input and output layers allow the network to reach a level of abstraction in learning and representing complex mappings.

Created on the assumption that the spelling-sound mapping system is not rule governed, but rather “quasiregular” (Seidenberg & McClelland, 1989), the Connectionist model of reading represents the statistical learning of spelling-sound correspondences (Seidenberg, 2005). The model computes the pronunciation of a word based on the consistency of the co-activated pronunciations for similarly spelled words. The consistency of spelling-sound mappings can be operationalized as the reliability of the pronunciation of the word’s medial vowel(s) and final consonant(s), also known as the word body or rime, across all monosyllabic words from a given rime neighborhood (e.g., Jared, 1997; 2002). Thus, a consistent word has a rime that is pronounced the same way in every word in which it occurs (e.g., –ATE, the rime of GATE, is pronounced consistently across all words sharing this rime: BATE, DATE, FATE, HATE, LATE, MATE, PATE, RATE, SATE). In contrast, an inconsistent word has a rime that is pronounced differently across different words (e.g., –OST, the rime of COST, is pronounced similarly in LOST, but differently in HOST, MOST and POST). Therefore, the lexical neighborhood of inconsistent words (e.g., COST) is divided into friends, rhyming neighbors that are pronounced like the given word (e.g., LOST), and enemies,
words that are orthographically similar, given the shared word body, but that are phonologically dissimilar (e.g., HOST, MOST and POST). The lexical neighborhood of consistent words contains only friends, whereas inconsistent words have both friends and enemies. Friends facilitate naming by activating the same phonological representation, yet enemies inhibit it; for example, in the case of an inconsistent word such as LOST, the model has to resolve the competition between the phonological activation generated by friends (e.g., COST) and enemies (e.g., HOST, MOST and POST). This competition for selection has a negative impact on naming latencies, and depending on the phonological activation chosen, on naming accuracy as well (e.g., Jared, 1997; 2002).

Consistency effects are found in both low and high frequency words as a function of the number and relative strength (i.e., frequency) of the rival pronunciations (Balota & Ferraro, 1993; Jared et al., 1990; Kay & Bishop, 1987). In other words, the ratio of friends to enemies modulates the size of the consistency effect (Jared, 1997; 2002; Jared et al., 1990). As the number of exposures to a given word increases, performance depends less on exposure to its similarly spelled neighbors. Similarly, high-frequency words produce more robust consistency effects when they have low-frequency friends and high-frequency enemies than when their enemies are lower frequency (Jared, 1997). Consistent words are less likely to be affected by frequency than inconsistent words in naming tasks, since there are no rival pronunciations to consider (e.g., Andrews, 1982; Brown, 1987; Hino & Lupker, 2000; Monsell, 1991; Seidenberg, 1992; Seidenberg et al., 1984). Furthermore, reading development research suggests that consistency effects are reduced with increased exposure to printed words (e.g., Alegria & Mousty, 1996; Weekes, Castles, & Davies, 2006; Zevin & Seidenberg, 2002).
Spelling-sound consistency, or the reliable mapping between the spelling of a word and its pronunciation, is referred to as feedforward consistency. Feedforward consistency is associated with lesser demands on cognitive resources relative to inconsistent mappings in children and adults during naming, rhyme priming and lexical decision tasks (e.g., Bolger, Hornickel, Cone, Burman, & Booth, 2008; Lacruz & Folk, 2004; Stone, Vanhoy, & Van Orden, 1997; Ziegler, Montant, & Jacobs, 1997; also see e.g., Lacruz & Folk, 2004; Pattamadilok, Morais, Ventura, & Kolinsky, 2007; Petrova, Gaskell, & Ferrand, 2011; Rastle, McCormick, Bayliss, & Davis, 2011; Ziegler & Ferrand, 1998; Ziegler, Petrova, & Ferrand, 2008 for evidence of consistency effects in the auditory modality). For example, children have more difficulty in reading and spelling inconsistent rather than consistent words (e.g., Alegria & Mousty, 1996; Weekes et al., 2006). Reading experience and skill modulate sensitivity to spelling-sound inconsistency, such that younger children show larger consistency effects than older children (e.g., Alegria & Mousty, 1996; Weekes et al., 2006), the same being true for poor readers compared to good readers (e.g., Brown, 1997; Stuart & Masterson, 1992). In contrast, other studies have found that the effect of consistency increases with reading skill, such that moderate and high skill readers show increased sensitivity to inconsistent versus consistent mappings relative to low skill readers (e.g., Bolger et al., 2008; Coltheart & Leahy, 1992; Laxon, Masterson, & Coltheart, 1991).

Consistency effects are not orthographic, but rather phonological in nature, so larger effects are more likely to appear in tasks that require phonological processing, such as word naming and rhyme priming, than in lexical decision tasks performed in the visual modality (Coltheart, Besner, Jonasson, & Davelaar, 1979; Waters & Seidenberg, 1985).
Also, the effects of spelling-sound consistency are independent of the effects of sound-spelling (feedback) consistency, or the likelihood of a sound to map onto different letter combinations, in both visual (e.g., Lacruz & Folk, 2004; Perry, 2003; Stone et al., 1997; Weekes et al., 2006; Ziegler et al., 1997) and auditory modalities (e.g., Miller & Swick; Pattamadilok et al., 2007; Ventura, Morais, Pattamadilok, & Kolinsky, 2004; Ziegler & Ferrand, 1998).

![Connectionist model of reading](image)

*Figure 2. Connectionist model of reading (Seidenberg & McClelland, 1989).*

**The Importance of Spelling-sound Consistency**

Since spelling-sound regularity (explicit grapheme-phoneme conversion rules) and consistency (implicit statistical learning of spelling-sound correspondence rules and exceptions) co-exist, much of the prior research on single word reading has confounded
the effects of regularity and consistency, showing that irregular and inconsistent words
typically take longer to name than regular consistent words (e.g. Baron & Strawson,
1976; Glushko, 1979; Gough & Cosky, 1977; Stanovich & Bauer, 1978). However,
spelling-sound consistency has an impact on naming latencies independent of GPC
regularity (Andrews, 1982; Jared, 1997; Kay & Bishop, 1987; Seymour, Aro, & Erskine,
2003; see also Coltheart & Leahy, 1992 and Stuart, Masterson, Dixon, & Quinlan, 1999
for evidence of the regularity effect on word naming and spelling independent of
consistency). Furthermore, the effect of consistency may predict naming latencies and
accuracy better than GPC regularity (Cortese & Simpson, 2000; see also Glushko, 1979;
Jared et al., 1990). Although the present research has also confounded consistency and
regularity to some extent, it uses a connectionist framework of reading to test whether
bilinguals recognize spelling-sound consistency in an L2 (i.e., English) that has either
less or more transparent orthography-phonology mappings than their L1. Non-
native English readers are often explicitly taught English grapheme-phoneme conversion rules
and exceptions to the rule through classroom instruction, oftentimes in an L1-speaking
environment. The current investigation tests whether non-native English readers who
have maintained L1 language dominance, but who are either immersed in an L2
environment, operationalized as active enrollment in an US higher education institution
(Study 2), or in an L1 environment, operationalized as active enrollment in a Dutch
higher education institution (Study 3), have implicitly learned the degree of spelling-
sound consistency they should expect in English, or whether they continue to rely on L1
spelling-sound consistency expectations.
This investigation builds upon previous studies testing bilinguals’ sensitivity to word-body enemies from the non-target language. Jared and Kroll (2001) found that English-French bilinguals who were fluent in French named English (L1) words with French word-body enemies more slowly relative to control words with no enemies following a French filler word naming block. The result was replicated with French-English bilinguals, although they were naming in their L2 (English). These findings suggest that bilinguals’ sensitivity to inter-lingual consistency is modulated by the overt co-activation of the non-target language. Furthermore, van Leerdam, Bosman and de Groot (2009) investigated whether Dutch-English bilinguals’ knowledge of intra- and inter-lingual enemy neighbors interfered with their activation of correct phonology when reading English (L2) words with inconsistent spelling-sound mappings. Participants were simultaneously presented with a printed English inconsistent word rime and a spoken word rime that either matched or did not match in phonology with each other. The authors found that bilinguals activated the incorrect phonological representation for the printed words when primed by an auditory rime that was either derived from an English (intra-lingual) enemy neighbor, or had Dutch (inter-lingual) enemy neighbors and was pronounced using Dutch phonology. These results suggest that non-native readers of English cannot inhibit the co-activation of within- and cross-language enemy neighbors when reading English inconsistent words.

The present set of studies adds to the current knowledge base by systematically manipulating a number of factors: the spelling-sound consistency of test items, the orthographic transparency (i.e., the degree of spelling-sound regularity and consistency encountered in a language) of bilinguals’ L1 and the co-activation level of the L1.
Bilinguals were primarily tested in the L2 (English, a relatively non-transparent orthography) using the visual modality to investigate their sensitivity to intra-lingual word body friends and enemies as a function of the orthographic transparency of their L1 (i.e., transparent: Spanish versus non-transparent: Chinese). A group of bilinguals were also tested on a cross-linguistic task that overtly co-activated the L1 (i.e., Dutch), a relatively transparent orthography (Seymour et al., 2003), to investigate its effect on the reading strategies adopted in English (L2). Such investigation of the interaction between L1 and L2 spelling-sound consistency expectations that bilinguals may experience during word reading in the L2 is an important step toward adapting the connectionist model to account for the role of orthographic depth in bilinguals who read two alphabetic orthographies or a logographic and an alphabetic writing system.

**Orthographic Depth**

Languages differ in the ways in which their writing systems map print to sound. Writing systems may be broadly categorized into three types of orthographies (i.e., alphabetic, syllabic and logographic) based on the units of spoken language they represent (Caravolas, 2007). Alphabetic orthographies, such as English, Spanish, and Dutch, represent phonemes through letters and letter clusters. Syllabic orthographies, such as Japanese Kanji, represent syllables through syllabographs (see Ellis et al., 2004 for a review). Syllabic orthographies will not be further discussed in this dissertation. Logographic orthographies represent monosyllabic morphemes (i.e., whole words) through characters (see Treiman & Kessler, 2007 for a review).
Alphabetic Orthographies

Alphabetic orthographies can be further categorized based on the degrees of regularity and consistency associated with their spelling-sound mappings (Seymour et al., 2003). The degrees of regularity and consistency vary as a function of the match between the number of phonemes found in the language and the number of graphemes contained in the orthography (Seymour, 2008). This measure of orthographic complexity is known as orthographic depth or transparency. Orthographic depth may be thought of as a continuum of spelling-sound regularity and consistency. At one end of this continuum are the orthographies with highly regular and consistent spelling-sound mappings, called shallow or transparent orthographies. For example, Spanish is an orthographically transparent or shallow language because one letter is consistently mapped to one sound. At the opposite end of this continuum are the orthographies with inconsistent spelling-sound mappings, called deep or opaque orthographies. English is an orthographically deep or opaque language because the same letter (or letter combination) can map to multiple sounds (e.g., the “ERE” rime in THERE [ðɛr], HERE [hɪr], WERE [wɚ]), resulting in words that are spelled inconsistently and/or that violate grapheme-to-phoneme correspondence rules (GPCs) and are therefore classified as “irregular”. Conversely, one English sound can map onto different letter combinations (e.g., the [æm] sound in SLAM [slaːm], LAMB [læm], DAMN [dæm]). Between these two extremes are orthographies with moderate degrees of inconsistency, such as Dutch (Seymour et al., 2003).

Orthographic depth has been claimed to set the optimal grain size (reading unit) that is used by readers in response to the level of consistency available in a given orthography.
(for a review of the “psycholinguistic grain size theory,” see Ziegler & Goswami, 2005 and Ziegler, Perry, Jacobs, & Braun, 2001). Even though both small and large reading units develop simultaneously (e.g., Burani, Marcolini, & Stella, 2002; Cuetos & Suárez-Coalla, 2009; Goswami, 1999; Goswami & East, 2000; Goswami et al., 1998; Orsolini, Fanari, Tosi, De Nigris, & Carrieri, 2006; Share, 1995) regardless of orthographic depth (Baluch & Besner, 1991; Burani, Marcolini, De Luca, & Zoccolotti, 2008; Frost, 1998; Lukatela, Feldman, Turvey, Carello & Katz, 1989; Pagliuca, Arduino, Barca, & Burani, 2008; Pagliuca & Monaghan, 2010; Sebastian-Galles, 1991), the choice of reading units may be more flexible in deep orthographies such as English (for a review of the “flexible-unit-size hypothesis” see Brown & Deavers, 1999 and Perry & Ziegler, 2000) than in shallow orthographies such as Spanish. That is because English requires readers to actively use both small and large grain sizes to ensure that words are read correctly regardless of the consistency of their spelling-sound mappings. Since readers of English are frequently alternating between small and large reading units, their grain size remains flexible through adulthood (Lehtonen & Treiman, 2007). In contrast, readers of Spanish and other shallow orthographies, may start with both small and large reading units, but the consistency of the spelling-sound mappings that they encounter on a daily basis leads them to rely to a large extent on small reading units, potentially causing their grain size to become less flexible over time. For example, Goswami, Ziegler, Dalton and Schneider (2003) compared the performance of English and German beginning readers on a non-word naming task that manipulated the reading unit size available to the readers by either blocking items by unit size or mixing items of different unit sizes. The authors found a strong switching cost when English readers named items of different unit sizes in the
mixed condition, but not in the German readers, suggesting that the readers of a shallow orthography (i.e., German) relied solely on a small grain size, whereas English readers switched between small and large reading units. A similar switching cost has been found in skilled English readers switching between small and large reading units in a word naming condition that mixed words and nonwords (e.g., Monsell et al., 1992).

The choice of reading units may be more flexible for readers of deep relative to shallow orthographies, but nonetheless, they develop a preference for a grain size as a result of experience, as is the case with readers of shallow orthographies, discussed above. The weak version of the “orthographic depth hypothesis” suggests that an important difference between shallow and deep orthographies is in the readers’ preference for using small versus large reading units (for a review of the “orthographic depth hypothesis” see Brunswick, 2010; Frost, 2005 and Katz & Frost, 1992). For example, readers of Spanish and other consistent alphabetic orthographies (e.g., Albanian, Dutch, Finnish, German, Greek, Italian, Romanian, Serbo-Croatian, Turkish, Welsh) favor small grain sizes, which have the letter as the reading unit (Ziegler & Goswami, 2005) because the shallow orthography enables them to efficiently rely on a letter-by-letter or syllable-by-syllable decoding strategy (Frost, 1994; Goswami, Gombert, & Fraca de Barrera, 1998; Katz & Feldman, 1983; Lukatela & Turvey, 1990). In English and other inconsistent alphabetic orthographies (e.g., Portuguese, French, Danish), readers are hypothesized to rely to a greater extent on large grain sizes (Frost, Katz, & Bentin, 1987) at rime, or whole word levels (Ziegler & Goswami, 2005). Martensen, Maris and Dijkstra (2000) have found that naming latencies in Dutch (which has a relatively shallow orthography) were better explained by the consistency of small
units of reading (i.e., onset, nucleus and coda) than naming latencies in English, which were best explained by the consistency of large units, such as the word body.

**Logographic versus Alphabetic Orthographies**

Among writing systems with different scripts, such as alphabetic (e.g., English) and logographic/morpho-syllabic (e.g., Chinese), there are differences in how orthography is mapped to phonology. Whereas in alphabetic orthographies graphic units (graphemes or letters) correspond to phonemes (sounds) that can be assembled incrementally to activate the phonological representation of a word, in morpho-syllabic orthographies these units (i.e., characters or morphemes) map onto whole syllables, which often constitute entire words. Thus, no assembly is possible or necessary within individual characters, which are recognized as whole units (Liu, Wu, & Chou, 1996; Paap & Noel, 1991; Perfetti & Liu, 2005; Perfetti, Liu, Fiez, Nelson, Bolger, & Tan, 2007). Each Chinese character contains a phonetic radical (i.e., encoding pronunciation) and a semantic radical (i.e., encoding meaning), which enable the automatic co-activation of phonological and semantic information during word recognition much like in alphabetic orthographies (e.g., Perfetti & Tan, 1998; Zhang, Perfetti, & Yang, 1999). But because the pronunciation of each Chinese character must be learned individually, Chinese is considered to have a larger grain size than alphabetic writing systems such as English, even through both Chinese and English may be described as having deep orthographies (Lee, Tsai, Su, Tzeng, & Hung, 2005). Because the Chinese writing system does not encode phonology at the phoneme level, children who learn Chinese will not tend to develop phonemic awareness without learning Pinyin (an alphabetic system used to teach the pronunciation of Chinese characters). Although exposure to Pinyin occurs over a short period of time (about 10
weeks at the beginning of primary school) prior to the introduction of traditional Chinese characters, Chinese children who are taught Pinyin score similarly to English monolinguals on a phoneme deletion task and perform better than Chinese children who learn Chinese characters by rote memorization (Huang & Hanley, 1995; Siok & Fletcher, 2001).

Reading Chinese does not solely imply lexical retrieval of phonology, but can also be modulated by regularity and consistency, as is the case in alphabetic orthographies. A Chinese character is defined as *regular* when there is a match between the pronunciation of the character and that of its phonetic radical, regardless of tonal differences, and *irregular* when the character has a different pronunciation than its phonetic radical (Fang, Horng, & Tzeng, 1986; Hue, 1992; see Lee et al., 2005 for a review). Only 39% of Chinese characters are regular (Lee, Huang, Kuo, Tsai, & Tzeng, 2010). Furthermore, a Chinese character is defined as *consistent* when all its orthographic neighbors that share the same phonetic radical have the same pronunciation; otherwise it is *inconsistent* (Fang et al., 1986; Lee et al., 2005). Similarly to English, Chinese consistency is also defined in terms of the relative number of friends and enemies (Lee et al., 2005; Lee et al., 2010). Both regularity and consistency effects in Chinese character naming have been reported, along with frequency-by-regularity and frequency-by-consistency interactions, suggesting that sublexical phonology has an impact upon reading Chinese characters (e.g., Fang, Horng, & Tzeng, 1986; Hue, 1992; Lee et al., 2010; Lee, Tsai, Chan, Hsu, Hung, & Tzeng, 2007; Lee, Tsai, Huang, Hung, & Tzeng, 2006; Lee et al., 2005; Liu, Chen, & Sue, 2003; Seidenberg, 1985).
The Advantage of a Small Grain Size

Numerous studies have shown that readers of shallow orthographies are at an advantage over readers of deep orthographies in the time needed to reach high levels of accuracy in word and non-word reading, as well as in the incidence and pattern of reading disability. The consistency of the spelling-sound mappings encountered in shallow orthographies appears to lie at the core of this advantage. Monolingual children learning to read relatively consistent writing systems such as Albanian (Hoxhallari, van Daal, & Ellis, 2004), Estonian (Viise, Richards, & Pandis, 2011), German (Frith, Wimmer, & Landerl, 1998; Landerl, 2000; Wimmer & Hummer, 1990), Greek (Goswami, Porposas, & Wheelwright, 1997; Porpodas, Pantelis, & Hantziou, 1990), Italian (Cossu, Gugliotta, & Marshall, 1995; Orsolini et al., 2006; Thorstad, 1991), Spanish (Cuetos & Suárez-Coalla, 2009; Defior, Martos & Cary, 2002; Goswami, Gombert, & De Barrera, 1998), Turkish (Öney & Durgunoglu, 1997) or Welsh (Ellis & Hooper, 2001; Spencer & Hanley, 2003) perform well in both word and nonword reading and spelling tasks by the middle or end of first grade, whereas English-speaking children do not reach comparable levels before three to six years of reading instruction (Bruck, Genesee, & Caravolas, 1997; Frith et al., 1998; Hanley et al., 2004).

It takes a relatively short amount of time to become skilled in reading an orthographic system based on regular and consistent spelling-sound mappings because a small grain size requires knowledge of fewer reading units (e.g., 26 graphemes) relative to a large grain size, which is associated with numerous bigrams and trigrams (Treiman & Kessler, 2007). In contrast, the need to choose between a small and a large grain size may come at a cost until children gain enough experience to calibrate the use of small and large
reading units. As a consequence, the relative transparency of beginning readers’ orthography is frequently associated with varying degrees of nonword decoding skills (Goswami et al., 1998) and different patterns of reading errors. For example, children learning to read transparent orthographies such as Finnish, German and Spanish have the highest accuracy scores on nonword decoding tasks, whereas English children have the lowest accuracy levels (e.g., Goswami et al., 1998; Landerl, 2000; Lopez & Gonzalez, 1999; Rack, Snowling, & Olson, 1992; Seymour et al., 2003; Wimmer & Goswami, 1994). Furthermore, readers also differ in the types of errors produced when reading words aloud as a result of the transparency of their orthography. Readers of shallow orthographies produce more mispronunciations in the form of pseudowords (e.g., Ellis et al., 2004; Ellis & Hooper, 2001; Wimmer & Goswami, 1994; Wimmer & Hummer, 1990), suggesting the use of a small grain size, whereas readers of English make more real-word substitution errors that are visually similar to the targets and failures to respond (Ellis et al., 2004; Seymour & Elder, 1986), suggesting the use of a large grain size.

There is a large performance gap between the least skilled readers of deep and shallow orthographies, with the poor readers of deep orthographies performing at much lower levels than the poor readers of shallow orthographies (Hanley et al., 2004). Furthermore, Paulesu and colleagues (2000) have found that the difference in performance between readers of shallow and deep orthographies does not disappear after the elementary school years, but can be found in adulthood using measures of both word and nonword reading speed.

Moreover, the incidence and patterns of reading disability are related to the orthographic complexity of the native language (e.g., Gholamain & Geva, 1999;
Goswami, 2000; Liberman, Shankweiler, Fischer, & Carter, 1974; Lindgren, De Renzi, & Richman, 1985; Ziegler & Goswami, 2005). For example, dyslexic readers of logographic writing systems (i.e., Chinese) demonstrate both phonological and orthographic processing deficits in reading Chinese characters (e.g., Ho, Chan, Lee, Tsang, & Luan, 2004; Meng, Tian, Jian, & Zhou, 2007; see Su, Klingebiel, & Weekes, 2010 for a review). Furthermore, dyslexic readers of deep alphabetic orthographies such as English evidence phonological deficits affecting their ability to read nonwords and spell (e.g., Frith, 1981; Snowling, 1998), with such difficulties persisting into adulthood (e.g., Bruck, 1992). In contrast, dyslexic readers of shallow orthographies (e.g., Dutch, German, Greek) show less marked phonological processing difficulties and their deficit tends to resolve by the end of second grade (e.g., De Jong & van der Leij, 2003; Landerl, Wimmer, & Frith, 1997; Landerl & Wimmer, 2000; De Gelder & Vroomen, 1991; Porposas, 1999; Wimmer, 1996). The evidence that phonological deficits are more likely to affect reading in deep than shallow orthographies is not surprising, considering that phonological awareness is a stronger predictor of reading development in deep alphabetic orthographies than in shallow alphabetic orthographies, which naturally promote high levels of phonological awareness through the consistency of their spelling-sound mappings (e.g., Georgiou, Parrila, & Papadopoulos, 2008; Landerl & Wimmer, 2000; Mann & Wimmer, 2002; Mayringer, Wimmer, & Landerl, 1998; Wesseling & Reitsma, 2000; Ziegler et al., 2010, but see Caravolas, Volin, & Hulme, 2005; Patel, Snowling, & de Jong, 2004 for evidence that phonological awareness is equally important in shallow and deep orthographies). Nonetheless, a study by Caravolas and Volin (2001) has suggested that the impact of orthographic depth on dyslexia may be less dramatic for
deep orthographies than it appears, since phonological deficits are also evidenced in the spelling of fifth grade dyslexic readers of a shallow orthography (i.e., Czech).

**The Flexibility of Grain Size in Bilinguals**

The process of reading increases in complexity for biliterate individuals relative to monolinguals, especially when bilinguals’ two alphabetic writing systems differ in the consistency of spelling-sound mappings. For example, individuals who are biliterate in Spanish and English must master two sets of consistency expectations and granularity preferences in addition to the typical factors contributing to successful word reading in monolinguals (i.e., oral language proficiency, phonological processing, and print awareness). The developmental literature points to orthographic complexity as an important potential predictor of adult bilinguals’ L2 word reading strategies (Dressler & Kamil, 2006; Katz & Frost, 1992). Bilinguals have been shown to adapt their reading strategy in response to the transparency of the target language orthography. For example, Meschyan and Hernandez (2006) have found that L2-dominant Spanish-English bilinguals showed greater brain activity in a region associated with phonological processing when reading words in a shallow orthography (i.e., Spanish), but greater activations in the brain regions involved in visual processing and word recoding (i.e., grapheme-phoneme conversion) when reading words in a deep orthography (i.e., English). The authors interpret their results as suggesting that their participants adopted a phonologically driven reading strategy for Spanish words and visually driven (lexical) reading strategy for English words, yet acknowledged that proficiency may have also played a role in the chosen strategy. Pitts and Hanley (2010) have also found that adult Spanish-English bilinguals were less likely than English monolinguals to use a
phonological reading strategy when reading English words. These findings suggest that bilinguals adapt their reading strategy in response to the orthographic transparency of the target language, developing a flexible grain size across the two languages. This means that becoming skilled in reading a second language that differs in orthographic depth from the L1 interacts with the grain size preference set by the L1, adding flexibility, but also inconsistency. What remains to be determined, however, is whether the adaptation of reading strategy in response to the L2 orthographic depth is influenced by an expectation of consistency derived from the transparency of L1 orthography.

**Cross-Linguistic Transfer of Word Reading Strategies**

For bilinguals to develop a flexible grain size in response to the orthographic depth of their two languages, they must first get past the initial stage of transferring reading skills from the L1 to the L2. The developmental interdependence hypothesis (e.g., Cummins, 1979; 1991) is one of the two premises guiding the current understanding of cross-linguistic transfer. It postulates that the level of L2 proficiency that can be achieved depends on the type of L1 competence attained at the time of initial exposure to the L2 (Cummins, 1979). In other words, cross-linguistic transfer from the L1 to the L2 is most efficient when L1 proficiency is high enough to support the acquisition of the L2.

There is evidence of cross-linguistic transfer at multiple levels of language, such as lexical knowledge: nouns and verbs (e.g., Marian & Kaushanskaya, 2007), word gender (e.g., Lemhöfer, Spalek, & Schriefers, 2008b), structure of compound words (e.g., Zhang, Anderson, Li, Dong, Wu, & Zhang, 2010) and grammar: syntactic structures (e.g., Chan, 2004). Word reading skills have been shown to transfer cross-linguistically both between and across writing systems (e.g., Abu-Rabia & Siegel, 2002; Bialystok, Luk, & Kwan,
2005; Comeau, Cormier, Grandmaison, & Lacroix, 1999; Geva & Siegel, 2000; Koda, 1989; Muljani et al., 1998; Wang, Park, & Lee, 2006; Wang, Perfetti, & Liu, 2005). For example, readers of a logographic native language such as Chinese have been shown to prefer to use a large grain size, associated with reading Chinese characters, when reading English (L2), rather than relying on English spelling-sound conversion rules to activate phonology (Tan et al., 2003), even though this strategy may slow down their learning of L2 spelling-sound consistencies. Furthermore, readers of Chinese are less sensitive to English phonology than are readers of Korean, a language with an alphabetic script that is not shared with English and with highly consistent letter-sound mappings (e.g., Holm & Dodd, 1996; Wang, Koda, & Perfetti, 2003; Wang et al., 2006). But even though phonological processing skills from languages such as Chinese and Korean transfer to English, orthographic processing skills do not transfer directly across writing systems that differ in visual form (e.g., Sun-Alperin, & Wang, 2011; Wang et al., 2006; Wang et al., 2005). Nonetheless, Chinese speakers may be more attentive to orthographic information in their L2 than speakers of Korean as a result of the increased demands on visual-orthographic processes imposed by reading a logographic system (Wang et al., 2003). In contrast, when bilinguals develop word reading in two alphabetic systems that share a script, any supporting skills acquired in the L1, such as print concepts (e.g., Manis, Lindsey, & Bailey, 2004; Tabors, Páez, & López, 2003), letters (e.g., Cárdenas-Hagan, Carlson, & Pollard-Durodola, 2007) phonological awareness (e.g., Comeau, Cormier, Grandmaison, & Lacroix, 1999; D’Angiulli, Siegel, & Serra, 2001; Durgunoglu, 2002; Durgunoglu, Nagy, & Hancin-Bhatt, 1993; Lindsey, Manis, & Bailey, 2003; Manis et al., 2004; Melby-Lervag & Lervag, 2011; Sun-Alperin, & Wang, 2011; Tabors et al., 2003)
and GPC rules (e.g., Bialystok et al., 2005) transfer to the L2. Only orthographic patterns that are language-specific are not likely to transfer (e.g., Sun-Alperin, & Wang, 2011).

The second premise of cross-linguistic transfer is contrastive analysis (e.g., Connor, 1996; Ellis, 1994). It proposes that the structural characteristics (e.g., phonology, syntax, semantics) of the L1 and L2 are classified into differences and similarities (Odlin, 1989). Structural differences create interference effects leading to errors (Lado, 1957), whereas structural similarities associated with top-down guidance from the L1 create facilitation effects, leading to faster acquisition rates (e.g., Abu-Rabia & Siegel, 2002; Cummins, 1979, 1991; Koda, 2005b; Mumtaz & Humphreys, 2002; Wang et al., 2005). Evidence of interference effects in English reading has been provided from L1 speakers of Hebrew (Wade-Woolley & Geva, 2000), Japanese, Russian (Wade-Woolley, 1999) and Italian (Nosarti et al., 2009). However, Melby-Lervag and Lervag (2011) found that factors such as having alphabetic scripts in both the L1 and L2 and receiving instruction in both languages moderate the cross-linguistic correlations in various language domains.

Furthermore, cross-linguistic studies with adult L2 learners suggest that the smaller the orthographic distance between the two languages, the more likely that the transferred capabilities will contribute positively to L2 reading (e.g., Akamatsu, 1999; Bialystok et al., 2005; Koda, 1989, 1999, 2005b; Muljani et al., 1998). Thus, the transferred competencies between two orthographically similar languages should require minimal L2 processing experience for fine-tuning and should benefit from spelling consistency (Koda, 2005a, b; Muljani et al., 1998).

Even though substantial cross-linguistic transfer is expected between similarly transparent orthographies, studies suggest that significant transfer also occurs from
shallow to deep orthographies, as evidenced by L1 word reading abilities in Spanish, Italian, Persian, Portuguese, and Urdu predicting L2 reading skills in English (e.g., Da Fontoura & Siegel, 1995; D’Angiulli et al., 2001; Durgunoglu et al., 1993; Gholamain, & Geva, 1999; Gottardo, 2002; Mumtaz & Humphreys, 2001). When transfer from a shallow to a deep orthography occurs, a heavier reliance on a small relative to a large grain size in reading L2 words is observed (Dressler & Kamil, 2006; Mumtaz & Humphreys, 2001). For example, Spencer and Hanley (2003) found that Welsh-English bilingual children reading English (L2) words showed a larger regularity effect than English children, suggesting a preference for using a sub-lexical reading strategy, which has proven successful in reading Welsh (L1) words. In contrast, when transfer from a deep to a shallow orthography occurs, inconsistency is added to the initial spelling-sound mappings, increasing lexical mediation in the L1 (Nosarti et al., 2009). Thus, the ability to read two orthographies with distinct depths impacts bilinguals’ reading strategies in each of their languages.

Furthermore, the transfer of reading strategies between two orthographies with distinct depths is modulated by language dominance. A recent study conducted by Botezatu, Misra and Kroll (in preparation) found that L1-dominant Spanish-English bilinguals showed a larger cost for naming English irregular and inconsistent words relative to regular and consistent words than L2-dominant Spanish-English bilinguals. Results suggest that L1-dominant bilinguals transfer reading strategies from a shallow L1 orthography to a deep L2 orthography. However, as dominance shifts (and proficiency likely increases), bilinguals may also shift their reading strategy to better fit the L2.
In the current work it is predicted that bilinguals who are biliterate in two orthographies will transfer their granularity preference from the L1 to the L2. In a recent study, Lemhöfer, Dijkstra, Schriefers, Baayen, Grainger, & Zwitserlood (2008a) found evidence that English (L2) processing was unaffected by orthographic depth of the L1, for native speakers of German, Dutch and French. However, Lemhöfer et al. did not manipulate spelling-sound consistency or test bilinguals with an L2 which is deeper than English (like Chinese). Furthermore, the Lemhöfer study only used behavioral measures, which are not as sensitive to subtle processing differences as neurocognitive measures. While it should be easier for any reader to process words with consistent spellings (i.e., where there are no rival pronunciations across similarly spelled words; see Glushko, 1979; Jared, McRae, & Seidenberg, 1990; Jared, 1997), spelling inconsistency may create greater problems for bilingual readers. Specifically, bilinguals whose native language exhibits spelling-sound consistency should experience more interference than native readers of a deep orthography, who likely resolve interference effects by adopting a larger grain size (either relying on the lexical route to generate the correct pronunciation of the whole word, or on the rime units, which are largely consistent). Bilinguals with a shallow L1 may not initially have a strategy of increasing granularity and may instead assess the consistency of individual grapheme-phoneme mappings. This method may work with consonants, which usually denote one to two phonemes across deep and shallow orthographies, but this approach would be inefficient with English vowels, which denote four to six phonemes across words and have a 51% consistency rate (Treiman, Mullennix, Bijeljac-Babic, & Richmond-Welty, 1995). The pronunciation of vowels changes relative to the surrounding letters, being more influenced by the following letters.
than the preceding ones (Rastle & Coltheart, 1999; Treiman & Zukowski, 1988).

Ultimately, bilinguals may construct a system of spelling-sound consistencies varying in granularity for each language as modulated by orthographic depth. However, the expectation of consistency resulting from L1 regularity may modulate L2 reading strategies (see Nosarti et al., 2009 for evidence that reading strategies in an L1 shallow orthography may also change as a result of learning a second alphabetic language with a deep orthography). The current dissertation seeks to confirm the hypothesis that reading strategy transfer occurs across languages with distinct levels of consistency in orthography-phonology mappings by testing bilinguals with distinct L1 orthographic depths (e.g., shallow: Spanish, Dutch; deep: Chinese) when reading in a deep L2 orthography (i.e., English).

**Boosting the Influence of the Non-target Language**

Studies seeking to boost the co-activation of the non-target language phonology in order to investigate its effect on word reading in the target language have often included words from that language in the stimulus set (e.g., Jared & Kroll, 2001; Jared & Szucs, 2002; Hermans, Ormel, van Besselaar, & van Hell, 2011; but see van Leerdam et al., 2009). The stimuli are oftentimes blocked by language. Mixed language conditions (i.e., containing words from bilinguals’ two languages) have also been used to boost the co-activation of the non-target language, producing a language switch cost relative to blocked language conditions (e.g., Botezatu et al., in preparation; Christofels, Firk, & Schiller, 2007). Furthermore, Brysbaert, Van Dyck and Van (1999) found that L2 targets preceded by masked L1 interlingual homophones (words that share phonology, but not
orthography or semantics across two languages) or pseudo-homophone primes were recognized more easily than controls. Similarly, L1 targets primed by masked L2 homophones were easier to recognize than controls (Van Wijnendaele & Brysbaert, 2002). The authors interpret the occurrence of cross-linguistic phonological priming as suggesting that both L1 and L2 grapheme-phoneme correspondences are non-selectively co-activated during the early stages of bilingual word recognition, implying that phonological mediation is a key component in word recognition (see Frost, 1998 for a review of the “strong phonological theory of visual word recognition”). These findings suggest that tasks requiring phonological priming or matching may benefit from the shared phonology of word stimuli across languages. This is an important premise for Experiment 2 of Study 3, which manipulated the phonological similarity between Dutch and English words in a cross-linguistic visual rhyme judgment task to investigate whether the expectation of spelling-sound consistency set by the presentation of Dutch prime words modulates Dutch-English bilinguals’ processing of English words that vary in the consistency of their spelling-sound mappings.

**Event-Related Potentials**

Event-related potentials (ERPs) can be used to index real-time brain dynamics underlying linguistic operations such as reading (Kaan, 2007; Steinhauer & Connolly, 2008). This technique complements behavioral measures such as reaction time (RT) and accuracy by providing a measure of neural activity involved in language processing as it unfolds over time. In this non-invasive technique, the naturally occurring electrical activity from assemblies of neurons (the electroencephalogram, or EEG) is detected by
using electrodes placed on the scalp. By time-locking the EEG to the presentation of different stimulus types and averaging over many trials, the electrical activity generated in response to specific events can be seen with millisecond precision (see Coles & Rugg, 1995; Kaan, 2007; Luck, 2005 and Molfese, Molfese, & Kelly, 2001 for reviews). Comparisons can then be made between waveforms generated by different types of stimuli. Features of the waveform called components (i.e., transient electric potential shifts) are characterized by measures of polarity (“N” for negative or “P” for positive), amplitude, latency and scalp topography. For example, the component called the “N100” is a negative-going deflection in the waveform peaking at about 100 milliseconds (ms), and the “P200” is a positive-going deflection in the waveform that peaks around 200 ms (see Figure 3). However, these labels are often based on convention, since components may vary in amplitude, duration, and latency with different stimulus manipulations (Key, Dove, & Maguire, 2005). Components that occur early in the time course of processing, within the first 200 ms post-stimulus presentation, are called exogenous and are determined by the external characteristics of the stimulus, such as frequency and color. Later, endogenous, components, occurring after 200 ms post-stimulus presentation, vary systematically based on task parameters, experimental instructions and the cognitive state of the participant. Therefore, exogenous components are relatively stable, whereas endogenous components show variability in response to the internal state and behavior of the participant (see Donchin, Ritter, & McCallum, 1978 and Näätänen, 1992, for further discussion).
In addition to their excellent temporal resolution, ERPs can be recorded concurrently with behavioral measures such as reaction time and accuracy of button presses, providing a glimpse at the cognitive processes that precede and succeed a behavioral response. However, the ERP technique has two important limitations: poor spatial resolution and artifact caused by movement. EEG recordings have relatively poor spatial resolution because any given electrode picks up electrical activity both directly beneath it, as well as from surrounding cortical areas, making it difficult to detect the neural generator responsible for the signal recorded. Movement, including eye blinks and speech, produces muscle artifact that significantly alters the EEG recordings. For this reason, experiments using ERP measures require participants to minimize movement, particularly eye blinks, causing fatigue and limiting the number and length of the tasks used in the
experiment. This further limits the type of experimental paradigms that can be used. Since naming tasks, or the reading of text passages produce muscle artifacts resulting from jaw movements and eye movements, respectively, preference is given to priming and lexical decision tasks, as they do not require overt articulatory responses and stimuli (i.e., words) can be presented one at a time, limiting eye movements.

**ERP Components of Visual Word Recognition**

The visual word recognition process involves analysis of the orthographic, phonological and semantic characteristics of written words. The time course of visual word recognition (for words presented without a grammatical context) spans approximately 500 milliseconds post-stimulus presentation, as follows: orthographic analysis peaks around 200 ms (Bentin, Mouchetant-Rostaing, Giard, Echallier & Pernier, 1999), followed by phonological analysis peaking at 300 ms (Bentin et al., 1999), and by semantic analysis, which peaks at around 400 ms (Kutas & Hillyard, 1980). There are a number of ERP components associated with each of these stages, which will be reviewed in turn to provide a general overview of the reading process as seen through the fine temporal resolution provided by this technique. However, only the components associated with phonological processing will be analyzed in the current set of studies.

Among the early components of visual word recognition, the literature identifies the P100, P150, N170, N200 and N250, generally associated with perceptual analysis and orthographic processing. The P100 reflects low-level perceptual analysis. It peaks at about 100 ms and is maximal over posterior regions (Dien, 2009; Key et al., 2005). Another early component is the P150, which peaks at about 150 ms and is maximal near the vertex (Dien, 2009). The P150 reflects sublexical orthographic processing, which
involves an early analysis of the shape of the letters that compose a word (Holcomb & Grainger, 2006). The component is associated with the beginning of grapheme-phoneme conversion procedures in single letters and has been found to be smaller for letter strings than for words and pseudowords (Proverbio, Vecchi, & Zani, 2004). Furthermore, the P150 appears to be sensitive to frequency, eliciting larger responses to high-frequency than low-frequency words (Proverbio et al., 2004). The N170 component peaks between 150 and 200 ms and is maximal over the posterior regions. Studies investigating the N170 have generated conflicting results. A larger N170 negativity has been found in consonant strings compared to words (Compton, Grossenbacher, Posner, & Tucker, 1991; McCandliss, Posner, & Givon, 1997), in correctly spelled compared to misspelled words (Sauseng, Bergmann & Wimmer, 2004), in words compared to symbols (McCandliss et al., 1997; Simon, Bernard, Lalonde, Rebaï, 2006) and in words compared to pseudowords (Maurer, Brandeis, & McCandliss, 2005). However, the component has also been found unable to distinguish between words, pseudowords and consonant strings, but to be larger for letter-based stimuli than non-letter stimuli (e.g., shapes, symbols and pseudo-letters; Bentin et al., 1999; Simon, Bernard, Largy, Lalonde, & Rebai, 2004). The component may be sensitive to different languages on the basis of difference in grapheme-phoneme conversion rules. For example, lower N170 amplitudes were found when monolingual French speakers saw Arabic words than when they saw French words and pseudowords in a lexical decision task (Simon et al. 2006). Moreover, in a study of Italian-Slovenian bilinguals, occipito-temporal scalp sites showed a bilateral response in the N1 latency range (160–180 ms poststimulus, corresponding to the N170 described in other studies) during the processing of Italian words and a left-sided response during Slovenian word
processing (Proverbio, Čok, & Zani, 2002). However, in a study by Grossi, Savill, Thomas and Thierry (2010), the N1 component was left lateralized in both early and late Welsh-English bilinguals. Furthermore, Proverbio, Adorni and Zani (2009) have investigated how simultaneous interpreters make lexical decisions about words and pseudowords in their first language and later-acquired, yet equally proficient, second and third languages. The results replicated previous findings that a distinction between L1 words and pseudowords was made as early as 160–180 ms at occipito-temporal sites. The simultaneous interpreters distinguished L2 words from pseudowords at about 260–320 ms, while L3 words were distinguished from pseudowords only at about 320–380 ms at posterior sites (Proverbio, Adorni & Zani, 2009). These results suggest that the N1/N170 is associated with the early stages of letter string processing and bigram analysis and is sensitive to orthographic depth and proficiency differences between native and non-native languages. A slightly later N200 component has also been associated with the early stages of orthographic decoding and is enhanced by attention to the letter patterns of words (Ruz & Nobre, 2008). Furthermore, an N250 component has been shown to reflect the processing of letters and letter clusters that primes and targets have in common (Holcomb & Grainger, 2006).

Phonological analysis follows the orthographic analysis stage and is typically associated with three ERP components: N320, N350 and N450. The N320 component has been linked to the sublexical mapping of orthography to phonology (Bentin et al., 1999; Proverbio et al., 2004; Simon et al., 2004), being modulated by the orthographic transparency of the language (Proverbio et al., 2004; Simon et al., 2006). Simon and colleagues (2006) have found that monolingual and Arabic-French bilingual readers of a
shallow orthography (i.e. French) elicited larger N320 amplitudes for French words and pseudowords than for words in Arabic, which differ in transparency and script from French orthography. The N320 has been further linked to the processing of inconsistent sound-spelling mappings, eliciting larger negativities for words with early inconsistent versus consistent sound-spelling mappings at centro-posterior sites (Perre & Ziegler, 2008). Therefore, the N320 is sensitive to the inconsistency of both spelling-sound and sound-spelling mappings. The N350 component, on the other hand, reflects the processing of phonology at the lexical level (Bentin et al., 1999) and is enhanced when the task requires a phonological decision (Ruz & Nobre, 2008; Spironelli & Angrilli, 2007). In phonological matching tasks, such as visual rhyme judgments, non-rhyming targets also elicit an enhanced negativity, known as the N450 component, compared to rhyming targets (Perez-Abalo, Rodriguez, Bobes, Gutierrez, & Valdes-Sosa, 1994; Rugg 1984a; 1984b). A similar enhanced negativity, peaking at about 400 ms post-stimulus, was found in the auditory modality, being elicited by non-rhyming versus rhyming targets primed by words varying in the spelling-sound consistency and orthographic overlap of the rime (Perre, Midgley & Ziegler, 2009). An in-depth review of the ERP components associated with the activation of phonology from print in the rhyme-priming paradigm will be described in the next section.

Semantic analysis constitutes the third stage of lexical processing and is associated with a negativity that peaks at about 400 ms post-stimulus onset (i.e., the N400 effect; see Kutas & Federmeier, 2011 for a review). The N400 component is sensitive to semantic incongruity, eliciting large negativities for words that are semantically incongruous with the preceding word or sentential context (e.g., Kutas & Hillyard, 1980; 1984; Kutas, Van
Petten & Kluender, 2006; Newman & Connolly, 2004; Perez-Abalo et al., 1994; but see Bornkessel, McElree, Schlesewski & Friederici, 2004, for evidence that the N400 is also sensitive to syntactic factors; and see Münte, Say, Clahsen, Schiltz, & Kutas, 1999 and Rodriguez-Fornells, Münte, & Clahsen, 2002 for evidence that the N400 is also modulated by morphology). The component is taken as an index of word and pseudoword processing, being affected by lexical properties such as orthographic neighborhood size (Holcomb, Grainger, & O’Rourke, 2002), frequency and predictability (Dambacher & Kliegl, 2007). The N400 has not only been elicited in the visual modality, but also in auditory and cross-modal tasks (e.g., Bentin, 1987; Bentin, Kutas, Hillyard, 1993; Connolly & Phillips, 1994; Holcomb & Anderson, 1993) and is qualitatively comparable across semantic and phonologic tasks (Khateb, Pegna, Landis, Mouthon, & Annoni, 2010).

**ERP Indices of Phonological Processing**

Visual rhyme judgment or “rhyme priming” has frequently been used with ERPs to evaluate the mapping of orthography to phonology, primarily in English (e.g., Grossi, Coch, Coffey-Corina, Holcomb, & Neville, 2001). This paradigm requires activation of phonology from text, making it a good fit for studying effects of spelling-sound consistency on word reading (Bolger et al., 2008), but does not impose a specific grain size, unlike phonological decision tasks, in which participants determine if a certain sound (phone) or syllable is present in a word (e.g., Proverbio & Zani, 2003; Proverbio et al., 2004). In visual rhyme priming, participants are asked to determine whether target letters, words, and/or pseudowords rhyme with their primes (e.g., Coch, George, & Berger, 2008a; Coch, Hart, & Mitra, 2008b; Rugg, 1984a). Participants typically perform
such tasks with ease; rhyme awareness develops as early as the age of 3 (e.g., Carroll & Snowling, 2001; Gathercole, Willis, & Baddeley, 1991; Kirtley, Bryant, MacLean, & Bradley, 1989; Sasisekaran & Weber-Fox, 2012) and is one of several factors that predict reading development (Bradley & Bryant, 1983; Gathercole et al., 1991; Scarborough, 2005; Treiman, 2000). Furthermore, visual rhyme judgment tasks activate phonology without requiring overt production, thus providing a fairly naturalistic paradigm for recording brain electrical activity while minimizing movement artifacts.

Studies using this paradigm have often focused on the ERP rhyming effect (RE). The RE observed in the visual modality consists of a substantially larger negative deflection to non-rhyming as compared to rhyming targets which begins 250-300 ms after target onset and peaks at about 400-450 ms (Grossi et al., 2001; Khateb, Pegna, Landis, Michel, Brunet, Seghier, & Annoni, 2007). The RE is primarily due to variations in two negative components, one of which is often referred to as the N450 (or N400) and a somewhat earlier peak around 350 ms (N350). The N450 tends to be maximal over midline and right temporo-parietal sites (Coch et al., 2008b; Grossi et al., 2001; Kramer & Donchin, 1987; Rugg, 1984a, 1984b; Rugg & Barrett, 1987) and has been described as an index of phonological processing (Treiman, 2000). It has been argued that the N450 is a phonological mismatch-related response, occurring when the target word’s phonology does not match the selected candidates in short-term memory (Khateb et al., 2007). Studies have reported a rhyming effect from age 7 to adulthood, suggesting that the processing systems indexed in visual rhyming paradigms mature relatively early and remain stable across development (Ackerman, Dykman, & Oglesby, 1994; Grossi et al., 2001).
The effect has been observed in English with letter name rhyming in beginning and skilled readers (Coch, Mitra, George, & Berger, 2011), as well as with word primes paired with both word and nonword targets (Coch et al., 2008b; Rugg, 1984a, 1984b). The effect has also been observed in native Spanish speakers performing a visual rhyme judgment task with Spanish word pairs (Perez-Abalo et al., 1994), as well as in native Chinese speakers making rhyme judgments of visually presented Chinese word pairs (L1) and English word pairs (L2; Chen, Lee, Kuo, Hung, & Cheng, 2010). Furthermore, Chen et al (2010) found that the N450 effects yielded by their participants in both L1 and L2 were correlated, suggesting that sequential bilinguals (who had begun L2 instruction at the age of 13 and who were tested in an L2 context) show similar phonological sensitivity in both the L1 and L2. Similar rhyming effects have been observed in the auditory modality in monolinguals (e.g., Coch, Grossi, Coffey-Corina, Holcomb, & Neville, 2002; Coch, Grossi, Skendzel, & Neville, 2005; Praamstra & Stegeman, 1993) and bilinguals (e.g., Aihua, Hao, & Yuchang, 2009), providing support to the phonological interpretation of the effect within the visual modality (Bentin et al., 1999; Penolazzi, Spironelli, Vio, & Angrilli, 2006; Rugg & Barrett, 1987). Furthermore, children and adolescents with phonological processing deficits show reduced N450 effects to rhyming letter (Lovrich, Cheng, & Velting, 2003; Lovrich, Simson, Vaughan, & Ritter, 1986) and word stimuli (Ackerman et al., 1994; McPherson, Ackerman, Holcomb, & Dykman, 1998; McPherson, Ackerman, Oglesby, & Dykman, 1996; Rüsseler, Becker, Johannes, & Münte, 2007).

The N450 is sensitive to interactions between orthography and phonology in alphabetic scripts, such that it is largest for orthographically dissimilar nonrhyming pairs
(e.g., *cake-gown*) and smallest for orthographically similar rhyming pairs (e.g., *take-fake*; Kramer & Donchin, 1987; Rugg & Barrett, 1987; Weber-Fox, Spencer, Cuadrado, & Smith, 2003). This interaction between orthography and phonology has also been observed in the auditory modality, with orthographic similarity between words in rhyming pairs facilitating responses, but having the opposite effects on non-rhyming pairs (e.g., Hillinger, 1980; Seidenberg & Tanenhaus, 1979, but see Damian & Bowers, 2010 and Pattamadilok, Perre, & Ziegler, 2011 for evidence that the interaction between phonology and orthography is task-specific and may be the result of a response strategy adopted to mediate a difficult phonological processing task). However, a study of visual rhyme priming in Chinese took advantage of the dissociation between orthography and phonology made possible by Chinese characters, which can rhyme with each other but have different orthographic structures (e.g., 拊 /ti/ and 低 /di/), showing that the N450 rhyming effect can be induced by phonological processing alone, irrespective of orthographic overlap (Chen et al., 2010).

The N350 is also sensitive to the phonological-orthographic incongruence of target words and is maximal over left anterior temporal sites (Grossi et al., 2001; Khateb et al., 2007). Larger N350s are elicited by non-rhyming prime-target pairs that do not share orthography than for rhyming prime-target pairs that share orthography (Kramer & Donchin, 1987; Weber-Fox et al., 2003). Intermediate amplitudes of the N350 are observed for pairs that match in orthography but do not rhyme and for pairs that rhyme but do not match in orthography (Weber-Fox et al., 2003).
Why Use ERPs to Investigate Cross-Linguistic Transfer

Past work evaluating language transfer effects in reading has relied primarily on behavioral methods, but recent studies suggest that ERPs may be sensitive to implicit second language processing that is masked in behavioral performance (e.g., McLaughlin, Osterhout & Kim, 2004; Tokowicz & MacWhinney, 2005). Therefore, ERP measures may reveal effects of transfer that are not evident in the behavioral data alone.

Furthermore, the rhyme judgment task is well suited for monolinguals and bilinguals alike, since bilinguals typically experience high levels of phonological awareness (e.g., Bialystok, 1988; Cromdal, 1999; Dickinson, McCabe, Clark-Chiarelli & Wolf, 2004; Durgunoglu, 1998; Verhoeven, 2007). The advantage of using a visual rhyme-priming paradigm to investigate the contribution of spelling-sound consistency and orthographic similarity to the activation of L2 (English) phonology is that it allows the study of the brain responses elicited by the same target word while manipulating the spelling-sound consistency of the prime and the phonological or orthographic overlap between the prime and the target. Because the critical comparisons are based on the ERPs elicited by the same targets, the priming paradigm yields much cleaner results than single word paradigms such as lexical decision (Perre, Midgley & Ziegler, 2009). Furthermore, the majority of the literature using a rhyme-priming paradigm has investigated the RE effect, comparing ERP waves elicited by rhyming responses to ERP waves elicited by non-rhyming responses. This may be problematic, as yes/no responses are inherently different and act as confounding variables in the analysis. To eliminate this design limitation, the current study is designed to compare rhyming conditions among themselves and non-rhyming conditions among themselves by holding the targets constant in both rhyming
and non-rhyming conditions and manipulating the spelling-sound consistency and orthographic similarity of the primes. Furthermore, this design ensures that an equal number of rhyming and non-rhyming trials are presented so that participants are not biased toward one type of response.

**The Current Studies**

The current studies used the visual rhyme-priming paradigm with behavioral and electrophysiological measures to investigate three research questions: 1) whether spelling-sound consistency and orthographic similarity have separate contributions in English monolinguals’ ability to make rhyme decisions in the visual modality; 2) whether the orthographic transparency of bilinguals’ native language has an impact on the reading strategy they adopt in a second language (i.e., English) that differs in orthographic depth from their L1; and 3) whether the overt co-activation of native language reading strategies impacts the reading strategy adopted in the second language (i.e., English) more than the covert co-activation bilinguals typically experience in L2 contexts when the L1 orthography is shallow and the L2 orthography is deep. To answer these research questions, three studies have been developed:

Study 1 aimed to answer the first research question by testing English monolinguals’ performance on an English rhyme judgment task that manipulated the spelling-sound consistency and orthographic similarity of the prime-target word pairs in both rhyming and non-rhyming conditions. Although previous studies have compared items with and without orthographic overlap in rhyme priming paradigms (e.g., Polich, McCarthy, Wang, & Donchin, 1983; Weber-Fox et al., 2003), this study differed in its attempt to
separate the contribution of orthographic similarity from the contribution of spelling-sound consistency. Study 1 also provided baseline comparison data for Study 2.

Study 2 investigated the second research question by testing the performance of Spanish-English and Chinese-English bilinguals on the same English rhyme judgment task used in Study 1. Participants in both groups were L1-dominant, sequential bilinguals (i.e., bilinguals with no consistent exposure to the L2 before the age of 6), whose L1 differed in spelling-sound consistency from English (L2). Spanish is an alphabetic orthography with highly consistent spelling-sound mappings, so Spanish-English bilinguals should have a preference for a small grain size. In contrast, Chinese has a logographic rather than an alphabetic orthography, so native Chinese readers should have few, if any, expectations for print-to-sound consistency. Studies 1 and 2 were both performed in an English-speaking environment to control for the effect of language environment.

Study 3 addressed the third research question by testing two groups of L1-dominant, sequential bilinguals, whose L1 orthography is shallow and L2 orthography is deep: Dutch-English bilinguals. One group performed the rhyme judgment task in English (L2) and served as baseline comparison for the second group, who made cross-linguistic (i.e., Dutch-English) rhyme judgments. Both groups of Dutch-English bilinguals were tested in their native language environment in the Netherlands at their University, which included instruction in English, to control for the effect of language environment. The Dutch-English rhyme judgment task was used to determine if the presence of both L1 and L2 words in the same task facilitates transfer of consistency expectations from a shallow L1 to a deep L2. Dutch was used in Study 3 because English and Dutch share a common
German root, which allowed sufficient rhyming stimuli to be generated in order to create a cross-linguistic reading context at the level of individual trials.

**Predictions**

If the results of the current studies are comparable to those found in the literature, then both monolingual and bilingual groups are expected to elicit the electrophysiological signature associated with phonological processing (i.e., Rhyming Effect or RE). Participants should elicit increased negativities peaking at around 350-450 ms post-stimulus in response to non-rhyming versus rhyming targets. The rhyming effect is expected not only to be replicated in English monolinguals performing the English visual rhyme-priming task, but also to be found in the Spanish-English, Chinese-English and Dutch-English bilinguals performing the same English rhyme judgment task, as well as in Dutch-English bilinguals performing a Dutch-English visual rhyme judgment task.

In performing the English visual rhyme-priming task, English monolinguals should show sensitivity to both spelling-sound consistency and orthographic similarity. If there is an effect of consistency, English monolinguals are expected to show slower response times, lower accuracy levels and larger N350/N450 amplitudes for consistent targets primed by inconsistent versus consistent rhyming words, as well as for inconsistent targets primed by inconsistent versus consistent non-rhyming words. Furthermore, if an effect of orthography is also present, then English monolinguals are expected to show faster response times, higher accuracy levels and reduced amplitudes for targets with converging cues from orthography and phonology compared to rhyming targets with no orthographic overlap. When targets with diverging cues from orthography and phonology are processed, English monolinguals should show increased response times, lower
accuracy levels and higher amplitudes compared to non-rhyming targets without orthographic overlap.

If bilinguals transfer reading strategies from the L1 to the L2, then bilinguals whose L1 orthography is shallow and L2 orthography is deep, as is the case for Spanish-English bilinguals, are expected to use a small grain size when reading English words, showing a preference for spelling-sound consistency. In contrast, Chinese-English bilinguals, whose L1 orthography is deeper than their L2 orthography, are expected to use a large grain size when reading English words regardless of spelling-sound consistency. In other words, if bilinguals’ transfer of word reading strategies from the L1 to the L2 is modulated by the orthographic distance between their two writing systems, then Chinese-English bilinguals should experience reduced sensitivity to consistency and orthographic similarity relative to Spanish-English bilinguals.

However, if the Spanish-English and Chinese-English bilingual groups tested in this study, residing in the US and being highly proficient in English, have adopted an English reading strategy, then they may resemble the English monolingual control group, providing evidence against granularity transfer. Moreover, if the Spanish-English and Chinese-English bilingual groups differ from the monolingual group in similar ways, then results may simply reflect general strategy differences in lower-proficiency readers.

Dutch-English bilinguals’ performance on the English rhyme-priming task should be comparable to that of Spanish-English bilinguals, unless either English proficiency or the overall language context plays a role. Although Spanish-English bilinguals in the US and Dutch-English bilinguals in the Netherlands have overall different immersion experiences, both participant groups were enrolled in universities where English was the
language of instruction and were expected to have similar proficiency levels in English. If language context plays a role, then Spanish-English bilinguals are expected to show faster response times and better accuracy than Dutch-English bilinguals, since the Spanish-English bilinguals are immersed in an English-speaking environment.

Since it should be more difficult to inhibit L1 reading strategies when both the L1 and the L2 are overtly co-activated within the same task (i.e., cross-linguistic rhyme judgment task) than when the task is performed solely in the L2 (i.e., English rhyme judgment task), consistency effects are expected to be enhanced for Dutch-English bilinguals performing the Dutch-English rhyme priming task than the English rhyme priming task. If consistency mediates competition between Dutch and English phonological activations, then Dutch-English bilinguals are expected to show slower response times, lower accuracy levels and a larger N350/N450 amplitude to English inconsistent versus consistent targets primed by rhyming and non-rhyming Dutch words. In contrast, if Dutch-English bilinguals show facilitation for consistent spelling-sound mappings in both L2-only and cross-linguistic contexts, then the transfer of consistency expectations from a shallow L1 to a deep L2 orthography is not modulated by the degree of co-activation of consistency expectations associated with the L1.

Overall, these studies have the potential to show whether bilinguals transfer spelling-sound consistency expectations from the L1 to the L2, or whether the reading strategy that they adopt in their L2 is solely a reflection of their non-native language proficiency. The studies can also reveal whether bilinguals’ preference for consistency in their L2 is modulated by the degree of L1 word reading strategy (i.e., grain size) co-activation. These studies are important in evaluating the role of the difference in orthographic depth
between bilinguals’ L1 and L2 writing systems in scaffolding their network of friends and enemies for L2 word rimes. The results may have implications for the current understanding of the process of reading in a second language and for the design of bilingual word reading models that account for orthographic depth.
Chapter 3

General Method

Participants

Results are presented for 27 English monolingual and 81 bilingual university students (31 male; mean age = 22.7; age range = 18 to 42 years). A total of 35 English monolinguals and 109 bilinguals had initially completed the study, but data from 36 participants were excluded from the analysis due to an insufficient number of trials. A subset of these individuals participated in each of the studies described in this dissertation, and the specific groups will be elaborated in more detail with each study. However, a basic overview of the participants is provided in this section.

Monolinguals were native English speakers with limited knowledge of a second language (no exposure to an L2 prior to the age of 6, less than 4 years of formal study of an L2 at the high school or college level, and no study abroad experience). Monolinguals were enrolled at the Pennsylvania State University. Bilingual participants were recruited from three groups of non-native English speakers: (1) highly proficient Spanish-English bilinguals enrolled at the Pennsylvania State University, (2) highly proficient Chinese-English bilinguals enrolled at the Pennsylvania State University, and (3) highly proficient Dutch-English bilinguals enrolled at the Radboud University, Nijmegen. Although the Dutch-English bilinguals differed in their overall language immersion context from the other bilingual groups, they were also in an academic environment where English was the language of instruction and typically reached high levels of English proficiency. In the present research the term “bilingual” is used liberally to refer to individuals who actively use two languages. The three groups of non-native English speakers were L1-dominant
sequential bilinguals with no consistent exposure to English before age of 6 and whose L1 was the primary language of instruction in school through eighth grade. Participants were recruited through campus announcements and/or psychology department subject pools and were paid $30 for 2 experimental sessions if tested in the US (€30 if tested in the Netherlands), or received course credit. All participants were right-handed, had normal or corrected-to-normal vision, and no history of neurological or language/reading disorders, according to self-report.

The criteria used to exclude participants’ data from the analysis varied by participant group. In the case of English monolinguals, individual participants’ data were excluded from the analysis if they did not have at least 70 percent artifact-free correct response trials per condition and if they did not respond accurately to at least 70 percent of the overall rhyming and non-rhyming conditions without showing a response bias. In the case of bilinguals, individual participants’ data were excluded from the analysis if they did not produce at least 20 correct, artifact-free responses per condition and if they did not have at least 60 percent overall accuracy in the rhyming and non-rhyming conditions.

Experimental Materials

The experimental materials used in the main experiment, a rhyme judgment task, are described in this section. Participants also completed other tasks, which are outlined in the procedure section.

The stimuli used in the rhyme judgment task included monosyllabic English and Dutch words. The spelling-sound consistency of English words (i.e., primes and targets in the English task; targets in the Dutch-English task) was varied systematically across conditions based on the Ziegler, Stone, & Jacobs (1997) norms. English words were
classified as either consistent or inconsistent based on rime neighborhoods of similar and contrasting pronunciations (e.g., Jared, 1997, 2002). A word was considered to be consistent if its medial vowel(s) and final consonant(s), also known as a rime, was pronounced the same way in every word in which it occurs (e.g., –ATE, the rime of GATE, is pronounced consistently across all words in which it appears: BATE, DATE, FATE, HATE, LATE, MATE, PATE, RATE, SATE). In contrast, a word was considered to be inconsistent if its rime is pronounced differently across different words (e.g., –OST, the rime of COST, is pronounced similarly in LOST, but differently in HOST, MOST and POST). Furthermore, the sound-spelling consistency of English words was held constant (i.e., inconsistent) across conditions and experiments to ensure that it did not factor into the processing differences observed across conditions. Since spelling-sound regularity could not be varied systematically along with consistency, the degree of spelling-sound regularity of English primes and targets was also coded so that the effect of regularity could also be evaluated in subsequent analyses of the data. Words were matched in length and frequency (see Tables A3 and A8 in Appendix A) using word frequency norms (CELEX for Dutch, Baayen, Piepenbrock, & Van Rijn, 1993; Kucera & Francis, 1967, for English). Words that English shares with Spanish, Chinese, or Dutch (i.e., cognates, interlingual homographs or homophones) were excluded from the English rhyme judgment task. Words that English shares with Dutch were excluded from the Dutch-English rhyme judgment task.

**Experimental Paradigm**

A visual rhyme judgment task was used to assess participants’ retrieval of phonology from orthography without overt pronunciation. The task is well suited for testing word-
reading strategies in both native and non-native speakers of English because the ability to make rhyme judgments develops early and is common across languages (e.g., Carroll & Snowling, 2001; Gathercole et al., 1991). Furthermore, rhyme-priming tasks have been previously used with the ERP technique (e.g., Grossi et al., 2001) because they do not require overt production, unlike naming tasks, eliminating a source of artifact. Another benefit of this experimental paradigm is that it can be easily used with manipulations of spelling-sound consistency and orthographic similarity of prime-target word pairs to investigate the reading unit size used by readers of varying skill in different conditions.

The studies included in this dissertation used an English rhyme judgment task to assess English word-reading strategies in English monolinguals (Study 1), Spanish-English (Study 2 Experiment 1) and Chinese-English bilinguals (Study 2 Experiment 2) and Dutch-English bilinguals (Study 3 Experiment 1). A Dutch-English rhyme judgment task was used to assess English word-reading strategies when the L1 is overtly co-activated in a second group of Dutch-English bilinguals (Study 3 Experiment 2). A general overview of the English and Dutch-English versions of the rhyme-priming task is presented here. A detailed explanation of the experimental conditions used in the English task is provided in Study 1. Study 3 includes details of the experimental manipulations used in the Dutch-English task.

Both the English and Dutch-English versions of the rhyme judgment tasks used equal numbers of rhyming (i.e., yes) and non-rhyming (i.e., no) trials to avoid cueing participants to ‘yes’ or ‘no’ responses. For the same reason, conditions that manipulated spelling-sound consistency, in the absence of orthographic similarity between prime-target pairs, were matched across on graphemic similarity (Van Orden, 1987; see Tables
A4 and A9 in Appendix A). Furthermore, two conditions in the English task that specifically manipulated orthographic similarity in the presence or absence of converging phonological cues (e.g., rhyming: RIGHT – FIGHT; non-rhyming: DOUGH – COUGH) were matched separately on graphemic similarity (see Table A4 in Appendix A).

Previous rhyme judgment studies have not controlled for orthographic similarity in this way, which may have caused orthographic similarity to act as a confounding variable in their results.

The English rhyme judgment task contained systematic manipulations of spelling-sound consistency and orthographic similarity of semantically unrelated prime-target word pairs in both rhyming and non-rhyming conditions. A set of 120 words served as targets (60 in the rhyming conditions and another 60 in the non-rhyming conditions). In the rhyming conditions, the target words always had consistent spelling-sound mappings (e.g., FIGHT), while the primes were classified into three categories: 1) words with consistent spelling-sound mappings that were orthographically similar to the target: RIGHT; 2) words with consistent spelling-sound mappings that were orthographically dissimilar with the target: WHITE and 3) words with inconsistent spelling-sound mappings that were orthographically dissimilar with the target: HEIGHT. In the non-rhyming conditions, the target words always had inconsistent spelling-sound mappings (e.g., COUGH), while the primes were classified into three categories: 1) words with inconsistent spelling-sound mappings that were orthographically similar with the target: DOUGH; 2) words with inconsistent spelling-sound mappings that were orthographically dissimilar with the target: CHILD and 3) words with consistent spelling-sound mappings that were orthographically dissimilar to the target: CHURCH.
The Dutch-English rhyme judgment task contained manipulations of the spelling-sound consistency of the English words (targets in this experiment). Manipulations of orthographic similarity between primes and targets were not possible in this task because of a high probability that shared rime spellings across Dutch-English prime-target pairs would belong to language ambiguous words (i.e., cognates or inter-lingual homographs). Care was taken so that no language ambiguous words were used as stimuli. Furthermore, the orthographic similarity of prime-target pairs was matched across rhyming and non-rhyming conditions to ensure that orthography did not cue participants to ‘yes’ or ‘no’ responses. A set of 72 Dutch words was used as primes across rhyming and non-rhyming conditions. Dutch words (e.g., KREET [kɾeɪt]) primed semantically unrelated English words that either had consistent (e.g., rhyming: TRAIT; non-rhyming: DARK) or inconsistent (e.g., rhyming: WEIGHT; non-rhyming: TEAR) spelling-sound mappings.

**Procedure**

Participants completed two individual testing sessions: an EEG session and a behavioral session scheduled no more than two weeks apart. All participants completed the EEG session prior to the behavioral session. After giving written consent and filling out a 20-item handedness questionnaire and a 31-item language history questionnaire (28 items for the bilingual groups, see Appendix B), participants were seated in a comfortable chair in a dimly lit, sound-attenuated and electrically shielded booth and were asked to perform a visual rhyme judgment task. The English monolingual, Spanish-English bilingual, Chinese-English bilingual and one of the Dutch-English bilingual participant groups performed an English rhyme judgment task. A second group of Dutch-English bilinguals performed a Dutch-English rhyme judgment task. In the English rhyme
judgment task, a continuous stream of 480 prime-target pairs (960 words) was presented, with brief breaks every 120 words. In the Dutch-English rhyme judgment task, a continuous stream of 288 prime-target pairs (576 words) was presented, with brief breaks every 144 words. Stimuli were presented in white capital letters in the center of a black screen at a viewing distance of approximately 48 inches. The sequence of events was as follows: a blank screen was presented for 500 ms, followed by the presentation of the prime for 350 ms, a 650 ms blank screen interstimulus interval (ISI), and the target, which remained on the screen for 350 ms. The target was followed by a 1000 ms blank screen and a central fixation cross (+) presented for 1500 ms (see Figure 4 for a schema of the event sequence). Participants were instructed to respond after each target by pressing one button of the response device if the target rhymed with its prime and another button of the response device if the target did not rhyme with its prime. Both speed and accuracy were stressed. The response hand (i.e., button pressed for rhyming vs. non-rhyming responses) was counterbalanced across participants. Participants were instructed not to blink or move unless the fixation cross was on the screen. A set of practice trials (30 for the English-only task; 14 for the Dutch-English task) preceded the presentation of the experimental stimuli. Participants were given feedback about their blink-performance after the practice trials and during the experimental breaks, if needed. None of the stimulus pairs used for practice appeared in the experimental sets. Both EEG and behavioral (RT and accuracy) measures were collected on each trial.

After the completion of the rhyme judgment task, participants were asked to perform two more tasks for which both EEG and behavioral (RT and accuracy) measures were collected. Participants performed a lexical decision task, during which they were
presented with monosyllabic and bisyllabic English words and pseudowords that either had regular and consistent or irregular and inconsistent spelling-sound mappings. Some of the English words were also cognates (similar in meaning and form) with Spanish words. The words appeared on the screen one at a time and participants were asked to decide whether or not each word was an English word. There was no overlap in experimental stimuli between the rhyme judgment and lexical decision tasks. Participants were then asked to complete a flanker task, in which they indicated whether a central arrow (→) pointed to the right or to the left. The arrow was presented along with four flanker arrows that were pointed to the same (→→→→→) or different direction (←←←←←).

After the three EEG tasks were completed, participants were asked to perform a paper and pencil word identification task. The task included a list of all the experimental items presented in the rhyme judgment task and participants were asked to cross off any of the words that were unknown to them. This task was used to determine if participants were familiar with the words presented in the rhyme judgment task. Bilinguals were also asked to read out loud the list of words in order to test whether they knew the correct pronunciations. Their responses were audio recorded and later coded for accuracy. Recordings of both response latencies and accuracy were made from the group of Dutch-English bilinguals who performed the cross-linguistic version of the rhyme judgment task.
The behavioral testing session occurred in a well-lit, sound-attenuated room of the lab. After reviewing the consent form from their initial testing session, participants were administered a battery of behavioral measures to assess their phonological working memory, reading skills, language proficiency and individual differences in cognitive resources. Monolingual participants were assessed in English and bilingual participants were assessed in their L1 in tasks measuring working memory and cognitive resources. However, bilinguals were tested in both the L1 and the L2 in tasks that assessed reading
skills and language proficiency. When a task was administered both in the L1 and English (L2), the L1 version always preceded the English version.

The tasks administered in session 2 are briefly summarized here, but will be described in more detail in the relevant studies. Participants were first administered a phonological working memory task in their L1 to assess their temporary storage of phonologically encoded information. Participants’ word and pseudo-word reading skills were then tested in their L1 (with the exception of Chinese, where pseudowords are not possible), followed by the L2 (English for the three bilingual groups) using timed and untimed tasks. These tasks were used to compare participants’ speed and accuracy in reading words and pseudowords (where relevant) across their native and non-native languages. Two picture-naming tasks, the first administered in the participants’ L1 and the second administered in English, were then used to assess participants’ language proficiency and dominance (Hoshino & Kroll, 2008; Jared & Kroll, 2001). Finally, participants’ individual differences in cognitive resources were assessed using the operation span task, which asked participants to perform a set of simple arithmetic operations and then recall L1 words presented after each equation.

**EEG Recording Procedure for Participants Tested in the US**

The EEG was recorded continuously with 29 tin electrodes mounted on an elastic electrode cap (Electro-Cap International, Eaton, OH). The electrode positions included 11 electrodes placed at the left (indicated by odd numbers) and right (indicated by even numbers) hemisphere frontal (F3/F4), central (C3/C4), temporal (T3/T4), parietal (P3/P4) sites, as well as frontal (Fz), central (Cz) and parietal (Pz) midline sites of the standard International 10-20 system. Ten additional electrodes were placed at the frontal (FPz) and
occipital (Oz) poles, the left and right hemisphere fronto-central sites (FC1/FC2, FC5/FC6), and centro-parietal sites (CP1/CP2, CP5/CP6). Another eight electrodes were placed at 33% of the distance from FPz to T3/T4 (FP1’/FP2’), 67% of the distance from FPz to T3/T4 (F7’/F8’), 33% of the distance from Oz to T3/T4 (O1’/O2’), and 67% of the distance from Oz to T3/T4 (T5’/T6’). Figure 5 shows the position of the electrodes.

Both the left (A1) and right (A2) mastoids were recorded. The left mastoid served as a reference for all the electrodes. The right mastoid was recorded to determine if there was any differential mastoid activity. The electro-oculogram (EOG) was recorded unipolarly: horizontal eye movements were measured by placing one electrode lateral to the right eye (HE) and vertical eye movements (blinks) were monitored by placing one electrode below the left eye (LE). Impedances were reduced to less than 5 kilo-ohms (kΩ) for the scalp and mastoid electrodes and less than 10 kΩ for the eye electrodes. The EEG was amplified by a SA Bioamplifier system with a bandpass of 0.1 to 40 hertz (Hz) and sampled continuously at a rate of 200 Hz. A 15-Hz low pass filter was applied to individual participant’s data prior to grand-averaging the data for presentation. This filtering step was not applied to the data used for the statistical analyses.
Figure 5. 33-channel electrode montage used in Studies 1 and 2. The grey scale used for the site locations denotes the analysis approach: open circles = midline, light gray = inner circle, medium gray = middle circle, and black = outer circle. See the data analysis section for a complete explanation of the analyses.

**EEG Recording Procedure for Participants Tested in the Netherlands**

The EEG was recorded continuously with 27 tin electrodes mounted in an elastic electrode cap (Electro-Cap International, Eaton, OH). The electrode positions included 12 electrodes placed at the left (indicated by odd numbers) and right (indicated by even numbers) hemisphere frontal (F3/F4, F7/F8), temporal (T5/T6), parietal (P3/P4) sites, as well as frontal (Fz), central (Cz) and parietal (Pz) midline sites of the standard International 10-20 system. In addition, seven electrodes were placed at anterior frontal (F3A/F4A, F7A/F8A), parietal (P3P/P4P), and midline (FzA) sites. Another eight electrodes were placed at sites that have been reported to be sensitive to language
manipulations (e.g., Holcomb & Neville, 1990): left and right anterior temporal sites (LAT and RAT: 50% of the distance between T3/T4 and F7/F8), left and right temporal sites (LT and RT: 33% of the interaural distance lateral to Cz), left and right temporoparietal sites (LTP and RTP: corresponding to Wernicke’s area and its right hemisphere homologue, 30% of the interaural distance lateral to a point 13% of the nasion-inion distance posterior to Cz), and left and right occipital sites (OL and OR: 50% of the distance between T5/T6 and O1/O2). This electrode montage has been used in previous studies (e.g., Van de Meerendonk, Kolk, Vissers, & Chwilla, 2010; Van Herten, Kolk, & Chwilla, 2005; Van Herten, Chwilla, & Kolk, 2006; Vissers, Chwilla, & Kolk, 2006). Figure 6 shows the position of the electrodes.

Both the left and right mastoids were recorded. The left mastoid served as a reference. The right mastoid was recorded to identify any differential mastoid activity. The electro-oculogram (EOG) was recorded bipolarly: horizontal EOG was measured by placing electrodes on the outer side of each eye, vertical EOG by placing electrodes below and above the right eye. The ground was placed on the forehead, between both eyes. Electrode impedance was less than 5 kΩ for the EOG electrodes, and less than 3 kΩ for the other electrodes. The EEG was sampled continuously at 500 Hz and filtered using a 30 Hz lowpass filter and a highpass with an 8-second time constant.
Data Analysis

Both behavioral and electrophysiological measures were used to evaluate performance on the rhyme judgment tasks. Reaction times and accuracy rates were measured based on correct button press responses recorded within the 200-2000 ms time window post-target onset. The experimental manipulations used in the English rhyme judgment task made possible the analysis of three within-subject variables: (1) condition (rhyming versus non-rhyming), (2) prime spelling-sound consistency (consistent versus inconsistent primes paired with rhyming consistent targets; consistent versus inconsistent primes paired with non-rhyming inconsistent targets) while the orthographic similarity of prime-target pairs is held constant and (3) prime-target orthographic similarity (orthographically similar versus orthographically dissimilar) while consistency is held
constant. Participants’ response times and accuracy rates across rhyming and non-rhyming conditions (also known as the rhyming effect, or RE) were compared using a repeated measures analysis of variance (ANOVA). Furthermore, the effects of spelling-sound consistency and orthographic similarity in facilitating participants’ rhyming and non-rhyming decisions (response times and accuracy rates) were evaluated using separate repeated measures ANOVAs. Since different targets were used across rhyming and non-rhyming conditions, rhyming and non-rhyming trials were not compared directly to evaluate the effects of spelling-sound consistency and orthographic similarity. For this reason, separate repeated measures ANOVAs were conducted for the rhyming and non-rhyming conditions, after an initial analysis of the RE.

The experimental manipulations used in the Dutch-English rhyme judgment task created two within-subject variables: condition (rhyming versus non-rhyming) and target spelling-sound consistency (consistent versus inconsistent). The RE effect was evaluated comparing participants’ response times and accuracy rates across rhyming and non-rhyming conditions using a repeated-measures ANOVA. Furthermore, to evaluate the effect of target word consistency on participants’ rhyming and non-rhyming decisions (reaction times and accuracy rates), a repeated-measures ANOVA with a 2 (condition: rhyming, non-rhyming) x 2 (target word consistency: consistent, inconsistent) design was used.

The raw EEG signal was time-locked to the presentation of the target. The EEG and EOG recordings were examined for muscle artifact and eye movements/blinks. Contaminated trials were removed from the analyses, along with incorrect response trials. Artifact rejection involved a two-stage process. The computer initially applied a standard
algorithm to reject artifact-filled trials and then the resulting output was manually checked and validated. To ensure that averages were based on artifact-free data, parameters of the standard algorithm were adjusted when needed. Separate ERP waves to rhyming and non-rhyming targets for each of the six conditions (four in the Dutch-English task) were averaged off line for each participant at each electrode site over a 1000 ms epoch. Averages were aligned to a 100 ms baseline preceding target onset and ended 900 ms post target onset.

For the English rhyme judgment experiments conducted in the US, repeated measures ANOVAs were performed separately for the within-subject factors of spelling-sound consistency (consistent versus inconsistent primes) and orthographic similarity (similar versus dissimilar prime-target pairs) in rhyming and non-rhyming conditions for the midline electrode sites (FPz, Fz, Cz, Pz, Oz) and for each of three concentric rings of lateral electrode sites (inner circle: FC1/FC2, C3/C4, CP1/CP2; middle circle: F3/F4, FC5/FC6, CP5/CP6, P3/P4; outer circle: FP1/FP2, F7/F8, T3/T4, T5/T6, O1/O2). Lateral electrode sites also included a factor of hemisphere (left versus right). For the English rhyme judgment experiment conducted in the Netherlands, the following electrode sites were used in the analysis: midline (FzA, Fz, Cz, Pz, Oz) and two concentric rings of lateral electrode sites (middle circle: F3A/F4A, F3/F4, LT/RT, LTP/RTP, P3/P4, P3P/P4P; outer circle: F7A/F8A, F7/F8, LAT/RAT, T5/T6, OL/OR).

For the Dutch-English rhyme judgment experiment, separate repeated measures ANOVAs were performed with the within-subject factors of spelling-sound consistency (consistent versus inconsistent targets) and condition (rhyming versus non-rhyming) for the midline electrode sites (FzA, Fz, Cz, Pz, Oz) and two concentric rings of lateral
electrode sites (middle circle: F3A/F4A, F3/F4, LT/RT, LTP/RTP, P3/P4, P3P/P4P; outer circle: F7A/F8A, F7/F8, LAT/RAT, T5/T6, OL/OR). Hemisphere (left versus right) was included as a factor in the analyses involving lateral electrode sites.

Only condition main effects and interactions of conditions with the other variables were reported, since main effects of electrode site or hemisphere, or interactions of only those terms reflect topographic differences in ERP patterns separate from the conditions that were manipulated in the current work. All results are reported as significant at the .05 level, unless otherwise noted. For comparisons with more than two levels, the Greenhouse-Geisser correction for nonsphericity was applied; uncorrected degrees of freedom and corrected $F$- and $p$-values were reported. Significant interactions were followed up with simple-effects analysis and/or post-hoc Bonferroni corrected $t$-tests where appropriate to better characterize the effects. Corrected $p$-values are also reported for the Bonferroni-corrected post-hoc $t$-tests.
Chapter 4

STUDY 1

Orthographic Consistency and Similarity in Monolingual Rhyme Processing

Study 1 examined the role of spelling-sound consistency and orthographic similarity in modulating English monolinguals’ strategies in extracting phonology from orthography. By evaluating the separate contributions of spelling-sound consistency and orthographic similarity to the process of making rhyme decisions in the visual modality, the present study adds to the current literature that investigates the role of orthographic overlap in visual rhyme judgments (e.g., Polich et al., 1983; Kramer & Donchin, 1987; Rugg & Barrett, 1987; Weber-Fox et al., 2003). The study aims to show that not only does spelling-sound consistency have a distinct contribution from orthographic similarity in facilitating visual rhyme judgments, but that it also interacts with orthographic similarity.

English monolinguals are expected to show sensitivity to both spelling-sound consistency and orthographic similarity. The effect of consistency should produce slower response times, lower accuracy levels and larger N350/N450 amplitudes for targets primed by inconsistent versus consistent rhyming and non-rhyming words. These effects are expected in response to the mismatch in spelling-sound consistency between rhyming and non-rhyming prime-target pairs given that inconsistent spelling-sound mappings have been associated with greater demands on cognitive resources relative to consistent mappings (e.g., Bolger et al., 2008; Lacruz & Folk, 2004; Stone et al., 1997; Ziegler et al., 1997). The effect of orthography should be evidenced by faster response times, higher accuracy levels and reduced amplitudes for rhyming targets with converging cues from
orthography and phonology (i.e., spelling-sound consistency) compared to rhyming targets with no orthographic overlap. In contrast, non-rhyming prime-target pairs with orthographic overlap in the absence of consistent spelling-sound mappings should produce increased response times, lower accuracy levels and higher amplitudes compared to non-rhyming targets without orthographic overlap. The orthographic similarity of prime-target word pairs has been previously shown to modulate rhyme judgments as a function of converging or diverging cues from phonology (e.g., Polich et al., 1983, Kramer & Donchin, 1987; Rugg & Barrett, 1987; Weber-Fox et al., 2003). Furthermore, the rhyming effect typically found in the ERP literature (e.g., Grossi et al., 2001; Weber-Fox et al., 2003) is expected to be replicated in this study, with participants demonstrating increased negativities peaking at around 350-450 ms post-stimulus in response to non-rhyming versus rhyming targets.

**Method**

**Participants**

Results are presented for 27 native speakers of English (9 male; mean age = 20.72 years; age range =18 to 27 years), who were students at the Pennsylvanian State University. All participants were right-handed, had normal or corrected-to-normal vision, and no history of neurological dysfunction, language or reading disorders. All were volunteers paid $30 for participation in two experimental sessions described below.

A total of 35 participants had initially completed the study, but data from 8 participants were excluded from the analysis. Data from seven of these participants were excluded due to an insufficient number of trials: Trials were lost due to excess muscle artifact (primarily from blinks) for four of these participants, whereas for three other
participants trials were lost due to technical difficulties during data collection. Data from one other participant were excluded because the participant did not finish the experiment.

Participants had limited knowledge of a second language, which for the purposes of the current study was operationalized as no exposure to an L2 prior to the age of 6, less than 4 years of formal study of an L2 at the high school or college level, and no study abroad experience.

**Stimuli**

Stimuli were monosyllabic English words matched in length and frequency (see Table A3 in Appendix A) and classified as either consistent or inconsistent based on the Ziegler et al. (1997) norms. All words were language unambiguous and had inconsistent sound-spelling mappings (i.e., the phonological representations that they activated could map onto different letter combinations), but they varied unsystematically in the regularity of their spelling-sound mappings. The words served either as primes or targets in a visual rhyme judgment task. The task contained 360 experimental primes, 120 filler primes and 120 targets (each repeated four times). To create the desired manipulations of spelling-sound consistency and orthographic similarity for the critical trials within both rhyming and non-rhyming conditions, the targets with consistent spelling-sound mappings were assigned to the rhyming conditions and the targets with inconsistent mappings were assigned to the non-rhyming conditions. A set of 120 fillers, which will be described below, prevented participants from being cued to ‘yes’ or ‘no’ responses based on the spelling-sound consistency of the target. The rhyming (R+) conditions (see Table 1 for the consistency and orthography manipulations employed in the rhyming conditions; and Table A1 in Appendix A for a list of all the rhyming experimental items) consisted of 60
consistency congruent (consistent prime – consistent target), orthographically similar pairs (R+C+O+, e.g., RIGHT – FIGHT), 60 consistency congruent (consistent prime – consistent target), orthographically dissimilar pairs (R+C+O–, e.g., WHITE – FIGHT) and 60 consistency incongruent (inconsistent prime – consistent target), orthographically dissimilar pairs (R+C–O–, e.g., HEIGHT – FIGHT). The non-rhyming (R–) conditions (see Table 2 for the consistency and orthography manipulations employed in the non-rhyming conditions; and Table A2 in Appendix A for a list of all the non-rhyming experimental items) consisted of 60 consistency congruent (inconsistent prime – inconsistent target), orthographically similar pairs (R–C+O+, e.g., DOUGH – COUGH), 60 consistency congruent (inconsistent prime – inconsistent target), orthographically dissimilar pairs (R–C+O–, e.g., CHILD – COUGH) and 60 consistency incongruent (consistent prime – inconsistent target), orthographically dissimilar pairs (R–C–O–, e.g., CHURCH – COUGH). All prime-target pairs were semantically unrelated. To prevent targets from cueing participants to ‘yes’ or ‘no’ responses, a set of 60 filler rhyming primes and a set of 60 filler non-rhyming primes were paired with the targets from the opposite experimental conditions to ensure that each target appeared in both rhyming and non-rhyming conditions (see Table A5 in Appendix A for a list of all the filler and practice items). Since each target was repeated four times (three times across experimental conditions and one time as a filler) across the experiment, the stimulus presentation was semi-randomized so that repetitions (including fillers) were at least 20 trials apart from each other. Three stimulus blocks were created (A, B, C), each experimental target or repeating prime appearing only once per block. The initial, second and third presentation of each experimental target was coded distinctively so that the
contribution of each block could be analyzed separately. Participants were randomly assigned to one of six presentation orders (ABC, ACB, BAC, BCA, CAB and CBA). Furthermore, the graphemic similarity (Van Orden, 1987) of prime-target pairs was also measured to ensure that orthographic information did not generally cue participants to ‘yes’ or ‘no’ responses (see Table A4 in Appendix A for the graphemic similarity values of each experimental condition).

### Table 1 English Rhyming Conditions (R+): Consistent Targets

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### Table 2 English Non-Rhyming Conditions (R−): Inconsistent Targets

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<td>CHURCH–COUGH</td>
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**Procedure**

Participants completed two individual testing sessions: an EEG session, followed by a behavioral session scheduled no more than two weeks apart. After giving written consent and filling out a 20-item handedness questionnaire and a 31-item language history questionnaire (all the questionnaire items can be found in Appendix B), participants were seated in a comfortable chair in a dimly lit, sound-attenuated and electrically shielded booth and were asked to perform a visual rhyme judgment task. The sequence of events of the English rhyme judgment task was previously described in the general method section (page 60).

After the completion of the rhyme judgment task, participants were asked to complete a paper and pencil word identification task, which included a list of all the experimental items presented in the rhyme judgment task. Participants crossed off any of the words that were unknown to them.

The behavioral testing session occurred no more than two weeks later in a well-lit, sound-attenuated room of the lab. After giving written consent, participants were administered a battery of behavioral measures to assess their phonological working memory, reading skills, language proficiency and individual differences in cognitive resources. The Memory for Digits subtest of the Comprehensive Test of Phonological Processing (CTOPP, Wagner, Torgesen, & Rashotte, 1999) was administered to assess participants’ temporary storage of phonologically encoded information in working memory. Participants’ reading ability was tested using the Sight Word Reading and Phonemic Decoding subtests of the Test of Word Reading Efficiency (TOWRE, Torgesen, Wagner, & Rashotte, 1999) to measure the number of words and pseudowords
that are read correctly in 45 seconds and the Word Identification and the Word Attack subtests of the Woodcock Reading Mastery Tests – Revised (Woodcock, 1987) to measure the untimed reading accuracy of words and pseudowords, respectively.

Furthermore, a picture-naming task was used to assess participants’ English proficiency. The task required participants to name line drawings of common objects while RT and accuracy were measured on each trial. Lastly, participants’ individual differences in cognitive resources were assessed using the operation span task, which asked participants to perform a set of simple arithmetic operations and then recall English words presented after each equation.

**EEG Recording Procedure**

Study 1 used the electrode setup and recoding procedure described on page 61.

**Data Analysis**

Both behavioral and electrophysiological measures were used to evaluate performance on the rhyme judgment tasks. Behavioral reaction times and accuracy were measured based on button press responses recorded during the EEG collection. Only correct responses recorded between 200 ms and 2000 ms post-target onset were considered valid. Participants’ response times and accuracy rates across rhyming and non-rhyming conditions were compared using a repeated measures analysis of variance (ANOVA). The effects of spelling-sound consistency and orthographic similarity in modulating participants’ rhyming and non-rhyming decisions (response times and accuracy rates) were evaluated using separate repeated measures ANOVAs.

EEG and EOG recordings were examined for muscle artifact and eye movements/blink. Trials that were contaminated or that had received incorrect responses
were removed from the analysis. To be included in the analyses, individual participants had to have responded accurately to at least 70 percent of rhyming and non-rhyming trials without showing a bias towards one response and to have had at least 70 percent artifact-free correct response trials within each of the six conditions. Separate ERP waves to rhyming and non-rhyming targets were averaged off line for each participant at each electrode site over a 1000 ms epoch. Averages were aligned to a 100 ms baseline preceding target onset and ended 900 ms post target onset.

The mean amplitude of the N400 component was calculated in the 250-600 ms temporal window post-target onset. The time window was selected to best capture the rhyming effect described in the rhyme priming literature (e.g., Chen et al., 2010; Coch et al., 2008a, b; Grossi et al., 2001; Khateb et al., 2007; Weber-Fox et al., 2003). In addition, smaller temporal windows were chosen based on visual observation of the grand averages to evaluate the effects of the consistency and orthographic similarity manipulations that were unique to the current sets of studies. Specifically, the mean amplitude of the spelling-sound consistency effect was evaluated for one window in the rhyming conditions (320-370 ms) and two windows in the non-rhyming conditions (0-100 ms and 350-450 ms). Furthermore, the mean amplitude of the orthographic similarity effect was evaluated for two windows within the rhyming conditions (200-410 ms and 450-620 ms) and three windows in the non-rhyming conditions (280-420 ms, 450-600 ms and 600-900 ms). Additionally, the peak latency difference between the orthographically similar and dissimilar word pairs was evaluated within both rhyming and non-rhyming conditions.

Repeated measures ANOVAs were performed separately for the within-subject
factors of spelling-sound consistency (consistent versus inconsistent primes) and orthographic similarity (similar versus dissimilar prime-target pairs) in rhyming and non-rhyming conditions for the midline electrode sites (FPz, Fz, Cz, Pz, Oz) and for each of three concentric rings of lateral electrode sites (inner circle: FC1/FC2, C3/C4, CP1/CP2; middle circle: F3/F4, FC5/FC6, CP5/CP6, P3/P4; outer circle: FP1/FP2, F7/F8, T3/T4, T5/T6, O1/O2). The concentric rings of lateral electrode sites also included a factor of hemisphere (left versus right).
Results

Behavioral Results

The behavioral results are shown in Figures 7 and 8. In a comparison of responses to all rhyming and all non-rhyming conditions, there was a significant main effect of condition on response times: $F(1, 26) = 22.16, p = .000$ and accuracy: $F(1, 26) = 4.78, p = .038$, indicating that participants were faster and more accurate in responding to rhyming relative to non-rhyming conditions.

Rhyming conditions. There was a significant effect of prime consistency on rhyming response times: $F(1, 26) = 8.43, p = .007$, indicating that participants were slower in responding to rhyming consistent target words when primed by inconsistent (e.g., R+C–O–HEIGHT–FIGHT) relative to consistent words (e.g., R+C+O–WHITE–FIGHT) with limited orthographic similarity to the target. However, participants were no more accurate in responding to rhyming targets primed by consistent than inconsistent words.

There was a significant effect of orthographic similarity on both rhyming response times: $F(1, 26) = 21.52, p = .000$ and accuracy: $F(1, 26) = 11.22, p = .002$, indicating that participants were faster and more accurate in responding to rhyming targets primed by words with high (e.g., R+C+O+RIGHT–FIGHT) rather than low (e.g., R+C+O–WHITE–FIGHT) degrees of orthographic similarity to the target. Recall that when prime-target orthographic similarity was varied, spelling-sound consistency was held constant.

Non-rhyming conditions. There was no effect of prime consistency on non-rhyme response times, but there was a significant main effect of prime consistency on response accuracy: $F(1, 26) = 6.13, p = .020$, indicating that participants were equally fast, but more accurate in responding to non-rhyming inconsistent target words when primed by
inconsistent (e.g., R–C+O– CHILD–COUGH) relative to consistent words (e.g., R–C–O– CHURCH–COUGH) with limited orthographic similarity to the target.

Furthermore, there was a robust effect of prime-target orthographic similarity on non-rhyming response times: $F(1, 26) = 150.05, p = .000$ and accuracy: $F(1, 26) = 46.85, p = .000$, indicating that participants were slower and less accurate in responding to non-rhyming targets primed by orthographically similar (R–C+O+ DOUGH–COUGH) than dissimilar words (e.g., R–C+O– CHILD–COUGH). Recall that when prime-target orthographic similarity was varied, spelling-sound consistency was held constant.

Even though the consistency effect appears to interact with condition (rhyming versus non-rhyming), it should be noted that rhyming and non-rhyming conditions differed in the spelling-sound consistency of the targets (consistent in the rhyming conditions; inconsistent in the non-rhyming conditions).

![Figure 7](image)

Figure 7. Mean reaction times (in ms) for rhyming and non-rhyming conditions. Error bars show 95% confidence intervals.
Electrophysiological Results

The waveforms elicited during the task showed a series of peaks consistent with previous visual word recognition studies. Specifically, there was a clear negative peak around 100 ms (N100), followed by a positive peak around 200 ms (P200), a negative peak between 300-500 ms (N400) and a positive peak between 500-900 ms (late positive component, or LPC). Differences between the waveforms for the critical conditions are described below.

**Rhyming effect (RE).** Figure 9 shows the ERP waveforms elicited by all rhyming and non-rhyming conditions at all 29 scalp electrode sites. This comparison is most similar to those presented in other studies evaluating the rhyming effect (RE). As in the past literature, the RE was most notable as a mean amplitude difference between the
conditions such that the non-rhyming condition elicited a larger negative waveform compared to the rhyming condition. The difference between rhyming and non-rhyming targets was biggest at about 400 ms post-target onset.

Between 250 and 600 ms, there was a significant main effect of condition for each set of electrode sites: midline: $F(1, 26) = 53.23, p = .000$; inner circle: $F(1, 26) = 43.46, p = .000$; middle circle: $F(1, 26) = 40.77, p = .000$; and outer circle: $F(1, 26) = 41.77, p = .000$. The results reflect the fact that the mean amplitude of the non-rhyming targets was more negative than the mean amplitude of the rhyming targets in the 250-600 ms window post-target onset.

There was also a significant interaction among condition, electrode and hemisphere over the middle circle: $F(3, 78) = 3.56, p = .032$. Further 2 (experimental condition) X 4 (electrode) ANOVAs were performed to investigate the three-way interaction over each hemisphere at the middle circle sites. There was a main effect of condition over the left hemisphere: $F(1, 26) = 34.47, p = .000$, as well as over the right hemisphere: $F(1, 26) = 35.5, p = .000$. Further paired t-tests revealed significant differences between rhyming and non-rhyming conditions over all middle circle left hemisphere electrode sites: F3: $t(26) = 4.46, p = .000$; FC5: $t(26) = 3.78, p = .001$; CP5: $t(26) = 6.42, p = .000$; and P3: $t(26) = 7.66, p = .000$; and over all middle circle right hemisphere electrode sites: F4: $t(26) = 5.73, p = .000$; FC6: $t(26) = 4.83, p = .000$; CP6: $t(26) = 5.45, p = .000$; and P4: $t(26) = 5.83, p = .000$. The results reflects the fact that the waves forming the RE were overall less negative in the frontal and fronto-central regions and more negative in the centro-parietal and parietal regions.
There was also a significant interaction between condition and electrode for each set of electrode sites: midline: $F(4, 104) = 7.1, p = .003$; inner circle: $F(2, 52) = 8.53, p = .002$; middle circle: $F(3, 78) = 9.26, p = .001$; and outer circle: $F(4, 104) = 5.43, p = .016$.

Post-hoc tests showed a wide distribution of the effect, such that there was a significant difference in the mean amplitude of rhyming and non-rhyming conditions at each electrode of the midline: FPz: $F(1, 26) = 38.78, p = .000$; Fz: $F(1, 26) = 32.04, p = .000$; Cz: $F(1, 26) = 53.22, p = .000$; Pz: $F(1, 26) = 49.45, p = .000$; Oz: $F(1, 26) = 26.16, p = .000$; inner circle: FC1/2: $F(1, 26) = 32.30, p = .000$; C3/4: $F(1, 26) = 41.43, p = .000$; CP1/2: $F(1, 26) = 52.72, p = .000$; middle circle: F3/4: $F(1, 26) = 28.15, p = .000$; FC5/6: $F(1, 26) = 24.81, p = .000$; CP5/6: $F(1, 26) = 44.88, p = .000$; P3/4: $F(1, 26) = 47.37, p = .000$ and outer circle: FP1/2: $F(1, 26) = 38.52, p = .000$; F7/8: $F(1, 26) = 17.26, p = .000$; T3/4: $F(1, 26) = 24.57, p = .000$; T5/6: $F(1, 26) = 29.60, p = .000$; O1/2: $F(1, 26) = 28.49, p = .000$. The rhyming effect covered the entire scalp and was focused over the central, centro-parietal and parietal electrode sites.

**Rhyming conditions.**

**Consistency effect.** Figure 10 shows the waveforms elicited by rhyming consistent target words primed by inconsistent versus consistent words (forming the consistency effect) at all 29 scalp electrode sites. The consistency effect was notable as a subtle mean amplitude difference between the rhyming conditions such that the consistent target words elicited a more negative waveform when primed by inconsistent relative to consistent words in the 320-370 ms time window, which produced a more negative peak at around 350 ms post-target onset (N350).
In the 320-370 ms (N350) time window, there was a significant interaction between condition and electrode over the inner circle: $F(2, 52) = 4.15, p = .043$ and middle circle electrode sites: $F(3, 78) = 4.34, p = .035$. The difference in this window appeared to peak at 350 ms, perhaps linking this effect to the N350 described in previous rhyme priming literature. Post-hoc tests showed a centro-parietal and parietal distribution of the consistency effect, such that there were significant differences in the N350 mean amplitude of the rhyming consistent target words when primed by inconsistent relative to consistent words at CP1/2: $F(1, 26) = 4.82, p = .037$ and P3/4: $F(1, 26) = 5.66, p = .025$. The result reflects the fact that consistent targets primed by inconsistent words (e.g., R+C–O–HEIGHT–FIGHT) elicited more negative N350 amplitudes relative to targets primed by consistent words (e.g., R+C+O–WHITE–FIGHT).

**Orthography effect.** Figure 11 shows the waveforms elicited by rhyming consistent target words primed by orthographically dissimilar relative to orthographically similar consistent words (forming the orthography effect) at all 29 scalp electrode sites. This comparison is similar to those presented in other studies evaluating the effect of orthographic similarity on rhyme judgments (e.g., Rugg & Barrett, 1987; Weber-Fox et al., 2003). The orthography effect was notable as a mean amplitude difference between rhyming conditions such that the orthographically similar word pairs elicited less negative waveforms compared to the orthographically dissimilar word pairs in the 200-410 ms temporal window, which produced a negative peak at around 400 ms post-target onset (N400). Additionally, the orthographically similar word pairs generated a less positive waveform relative to the orthographically dissimilar word pairs in the 450-620
ms window post-target onset, producing a positive peak at around 600 ms post-target onset (LPC).

**Mean amplitude difference.** In the 200-410 ms (N400) window, there was a significant main effect of condition for each set of electrode sites: midline: $F(1, 26) = 27.3, p = .000$; inner circle: $F(1, 26) = 25.03, p = .000$; middle circle: $F(1, 26) = 22.91, p = .000$ and outer circle: $F(1, 26) = 15.99, p = .000$. This result reflects the fact that the mean amplitude of the orthographically dissimilar condition (e.g., R+C+O– WHITE– FIGHT) was more negative than the orthographically similar condition (e.g., R+C+O+ RIGHT–FIGHT) in the 200-410 ms window post-target onset. The effect was widely distributed, covering the entire scalp.

In the 450-620 ms (LPC) window, there was a significant main effect of condition for each set of electrode sites: midline: $F(1, 26) = 11.03, p = .003$; inner circle: $F(1, 26) = 9.72, p = .004$; middle circle: $F(1, 26) = 7.08, p = .013$ and outer circle: $F(1, 26) = 4.57, p = .042$. This result reflects the fact that the mean amplitude of the orthographically similar condition (e.g., R+C+O+ RIGHT–FIGHT) was less positive than the orthographically dissimilar condition (e.g., R+C+O– WHITE–FIGHT) in the 450-620 ms window post-target onset.

Furthermore, in the 420-620 ms (LPC) window there was a significant interaction between condition and electrode over the midline: $F(4, 104) = 3.1, p = .05$. Further post-hoc tests showed that there was a significant difference between the mean amplitudes elicited by the orthographically dissimilar and similar conditions at FPz: $F(1, 26) = 4.53, p = .043$; Fz: $F(1, 26) = 7.92, p = .009$; Cz: $F(1, 26) = 12.59, p = .002$ and Pz: $F(1, 26) = 9.69, p = .004$. The result reflects the fact that the orthography effect in the 450-620 ms
window was most prominent towards the central scalp and minimal over the midline occipital site.

There was also a significant interaction among condition, electrode and hemisphere over the middle circle: $F(3, 78) = 3.55, p = .034$. Further 2 (experimental condition) X 4 (electrode) ANOVAs were performed to investigate the thee-way interaction over each hemisphere at the middle circle sites. There was a main effect of condition over the left hemisphere: $F(1, 26) = 8.7, p = .007$ and over the right hemisphere: $F(1, 26) = 4.47, p = .044$. Paired t-tests indicated a significant difference between the mean amplitudes elicited by the orthographically dissimilar and similar conditions at CP5: $t(26) = 3.13, p = .016$ and P3: $t(26) = 3.17, p = .016$, as well as a trend toward a significant difference at F4: $t(26) = 2.44, p = .088$. The result reflects the fact that the orthography effect in the 450-620 ms time window was weakest over the right hemisphere of the middle circle electrode sites.

**Peak latency difference.** In addition to evaluating the mean amplitude differences for the orthography effect, there appeared to be a peak latency difference such that the orthographically dissimilar rhyming condition (i.e., R+C+O–WHITE–FIGHT) elicited a negative peak at about 400 ms post-target onset: Followed by the orthographically similar rhyming condition (i.e., R+C+O+RIGHT–FIGHT), which peaked at around 500 ms post-target onset. There was a significant main effect of condition at each set of electrode sites: midline: $F(1, 26) = 9.01, p = .006$; inner circle: $F(1, 26) = 5.77, p = .024$; middle circle: $F(1, 26) = 7.68, p = .010$ and outer circle: $F(1, 26) = 16.71, p = .000$. This reflects the fact that the effect of orthography produced two distinct negative peaks.
Furthermore, there was a significant interaction among condition, electrode and hemisphere: $F(1, 26) = 6.24, p = .000$ over the outer circle. Further 2 (experimental condition) X 5 (electrode) ANOVAs were performed to investigate the three-way interaction over each hemisphere at the outer circle sites. There was a main effect of condition over the left hemisphere: $F(1, 26) = 23.8, p = .000$. Paired t-tests showed a significant difference between the peak latencies of orthographically dissimilar and similar conditions at FP1: $t(26) = -2.56, p = .017$; F7: $t(26) = -2.5, p = .019$; T5: $t(26) = -2.28, p = .031$; O1: $t(26) = -2.65, p = .014$ and T4: $t(26) = -3.76, p = .001$. The results reflect the fact that the peak latency difference was focused over the left hemisphere in the outer electrode circle, but had a wide distribution over the midline, inner and middle circle electrode sites.
Figure 9. Grand average event-related potentials elicited by rhyming conditions (solid lines) and non-rhyming conditions (dotted lines) from all 29 scalp electrodes. Data are plotted from 100 ms prior to the onset of the target word until 900 ms post-target onset, and negative is plotted up. The RE effect is observed within the 250-600 ms time window post-target onset.
Figure 10. Grand average event-related potentials elicited by rhyming consistency incongruent (solid lines) and consistency congruent conditions (dotted lines) from all 29 scalp electrodes. Data are plotted from 100 ms prior to the onset of the target word until 900 ms post-target onset, and negative is plotted up. The consistency effect is observed within the 320-370 ms window post-target onset.
Figure 11. Grand average event-related potentials elicited by rhyming orthographically dissimilar (solid lines) and orthographically similar conditions (dotted lines) from all 29 scalp electrodes. Data are plotted from 100 ms prior to the onset of the target word until 900 ms post-target onset, and negative is plotted up. The orthography effect is observed within the 200-410 and 450-620 ms temporal windows post-target onset.
Non-rhyming conditions.

**Consistency effect.** Figure 12 shows the waveforms elicited by non-rhyming inconsistent target words primed by consistent versus inconsistent words (forming the consistency effect) at all 29 scalp electrode sites. The consistency effect was notable as a subtle mean amplitude difference between the non-rhyming conditions such that the inconsistent target words elicited a more negative waveform when primed by consistent relative to inconsistent words in the 0–100 ms time window, producing a negative peak at around 100 ms post-target onset (early N100) and when primed by inconsistent relative to consistent words in the 350–450 ms temporal window, producing a negative peak at around 400 ms post-target onset (N400).

In the 0–100 ms (early N100) temporal window, there was a significant interaction between condition and hemisphere over the inner circle: $F(1, 26) = 10.13, p = .004$ and middle circle: $F(1, 26) = 6.56, p = .017$ and a trend toward a significant interaction between condition and hemisphere over the outer circle: $F(1, 26) = 3.14, p = .088$. Further post-hoc tests over the inner circle showed a left hemisphere distribution of the effect such that there was a trend toward a significant mean amplitude difference between the consistency congruent and incongruent conditions over the left hemisphere: $F(1, 26) = 3.62, p = .068$, but not over the left hemisphere. Post-hoc tests over the middle circle showed a main effect of condition that did not reach significance over either hemisphere. The effect reflects the fact that in the 0-100 ms time window, consistency incongruent non-rhyming trials (e.g., R–C–O– CHURCH–COUGH) elicited more negative mean amplitudes relative to the consistency congruent non-rhyming trials (e.g., R–C+O– CHILD–COUGH) over the left hemisphere of the inner circle. The same pattern of
results was observed over the left hemisphere of the middle circle, even through the effect did not reach significance.

In the 350-450 ms (N400) analysis window, there was a trend toward a significant three-way interaction among condition, electrode and hemisphere over the inner circle: $F(2, 52) = 3, p = .060$. This set of results reflects the fact that the consistency congruent non-rhyming conditions (e.g., R–C+O– CHILD–COUGH) elicited slightly more negative N400 amplitudes relative to the consistency incongruent non-rhyming conditions (e.g., R–C–O– CHURCH–COUGH) over the inner circle.

There was also a significant interaction between condition and hemisphere over the middle circle: $F(1, 26) = 5.53, p = .027$ and a trend toward a significant interaction over the outer circle: $F(1, 26) = 3.45, p = .074$. Further post-hoc tests over the middle circle showed a right hemisphere distribution of the consistency effect, such that there was a trend toward a significant mean amplitude difference between the consistency congruent versus incongruent conditions over the right hemisphere: $F(1, 26) = 2.99, p = .095$, but not over the left hemisphere.

**Orthography effect.** Figure 13 shows the waveforms elicited by non-rhyming inconsistent target words primed by orthographically dissimilar versus orthographically similar inconsistent words (forming the orthography effect) at all 29 scalp electrode sites. This comparison is similar to those presented in other studies evaluating the effect of orthographic similarity on non-rhyme judgments (e.g., Rugg & Barrett, 1987; Weber-Fox et al., 2003). The orthography effect was notable as a mean amplitude difference between non-rhyming conditions such that the orthographically similar word pairs elicited a less negative waveform compared to the orthographically dissimilar word pairs in the 280-
420 ms time window, producing a negative peak at around 400 ms post-target onset (early N400). Furthermore, the orthographically similar word pairs elicited a more negative waveform compared to the orthographically dissimilar word pairs in the 450-600 ms time window, producing a negative peak at around 450 ms post-target onset (late N400). Additionally, the orthographically similar word pairs elicited a more positive waveform compared to the orthographically dissimilar word pairs in the 600-900 ms time window, producing a positive peak at about 600 ms post-target onset (late part of the LPC).

**Mean amplitude difference.** In the 280-420 ms (early N400) window, there was a significant main effect of condition for each set of electrode sites: midline: $F(1, 26) = 39.26, p = .000$; inner circle: $F(1, 26) = 34.47, p = .000$; middle circle: $F(1, 26) = 40.91, p = .000$ and outer circle: $F(1, 26) = 52.69, p = .000$. The result reflects the fact that the mean amplitude of the orthographically dissimilar condition (e.g., R–C+O– CHILD–COUGH) was more negative than the mean amplitude of the orthographically similar condition (e.g., R–C+O+ DOUGH–COUGH) in the 280-420 ms time window post-target onset.

There was a significant interaction among condition, electrode and hemisphere over the inner circle: $F(2, 52) = 6.05, p = .004$ and outer circle: $F(4, 104) = 2.98, p = .049$. At the inner circle sites: Further 2 (experimental condition) X 3 (electrode) ANOVAs were performed to investigate the thee-way interaction over each hemisphere. There was a main effect of condition over both the left hemisphere: $F(1, 26) = 27.78, p = .000$ and the right hemisphere: $F(1, 26) = 34.55, p = .000$. Over the left hemisphere, paired-samples t-tests revealed significant differences between the orthographically dissimilar versus
orthographically similar conditions at FC1: \( t(26) = -5.41, p = .000 \); C3: \( t(26) = -5.0, p = .000 \) and CP1: \( t(26) = -4.53, p = .000 \). Over the right hemisphere, paired-samples t-tests revealed significant differences between the orthographically dissimilar versus orthographically similar conditions at FC2: \( t(26) = -5.82, p = .000 \); C4: \( t(26) = -5.97, p = .000 \) and CP2: \( t(26) = -4.77, p = .000 \). The result reflects the fact that the mean amplitude of the orthographically dissimilar condition is more negative and slightly larger relative to the orthographically similar condition over the right hemisphere of the inner circle at fronto-central and central electrode sites.

At the outer circle sites: Further 2 (experimental condition) X 5 (electrode) ANOVAs were also performed to investigate the three-way interaction over each hemisphere. Over the left hemisphere, there was a main effect of condition: \( F(1, 26) = 34.55, p = .000 \). Further paired-samples t-tests showed significant differences between the orthographically dissimilar versus orthographically similar conditions at FP1: \( t(26) = -4.4, p = .000 \); F7: \( t(26) = -5.31, p = .000 \) and T3: \( t(26) = -4.04, p = .000 \), but not at T5 and O1. Over the right hemisphere, there was a main effect of condition: \( F(1, 26) = 36.33, p = .000 \). Further paired-samples t-tests showed significant differences between the orthographically dissimilar versus orthographically similar conditions at FP2: \( t(26) = -3.78, p = .005 \); F8: \( t(26) = -4.37, p = .000 \); T4: \( t(26) = -4.84, p = .000 \); and T6: \( t(26) = -4.41, p = .000 \). The results indicate that at the outer circle sites, the orthography effect had a fronto-temporal distribution over the left hemisphere, but a wide distribution over the right hemisphere.

There was also a significant interaction between condition and hemisphere over the middle circle: \( F(1, 26) = 12.07, p = .002 \). Further post-hoc analyses showed a mean
amplitude difference between the orthographically similar and dissimilar conditions over the left hemisphere: $F(1, 26) = 22.17, p = .000$, as well as over the right hemisphere: $F(1, 26) = 42.88, p = .000$. This result reflects the fact that the orthography effect was largest over the right hemisphere in the 280-420 window post-target onset.

In the 450-600 ms (late N400) window, there was a trend toward a significant main effect of condition over the midline: $F(1, 26) = 4.08, p = .054$ and a significant main effect of condition over the inner circle: $F(1, 26) = 16.44, p = .000$; middle circle: $F(1, 26) = 17.14, p = .000$ and outer circle: $F(1, 26) = 7.71, p = .010$. This set of results reflects the fact that in the 450-600 ms window post-target onset, the mean amplitude of the orthographically similar condition (R–C+O+ DOUGH–COUGH) was more negative than the orthographically dissimilar condition (R–C+O– CHILD–COUGH).

Furthermore, there was a significant interaction between condition and electrode over the midline: $F(4, 104) = 6.33, p = .009$; inner circle: $F(2, 52) = 6.17, p = .008$ and outer circle: $F(4, 104) = 5.46, p = .015$. Further post-hoc tests showed that there was a significant difference between the mean amplitudes elicited by the orthographically dissimilar and similar conditions at some of the midline sites: Cz: $F(1, 26) = 10.21, p = .004$; Pz: $F(1, 26) = 10.22, p = .004$; inner circle sites: FC1/2: $F(1, 26) = 5.22, p = .031$; C3/4: $F(1, 26) = 19.69, p = .000$; CP1/2: $F(1, 26) = 18.54, p = .000$; and some of the outer circle sites: T3/4: $F(1, 26) = 10.13, p = .004$; T5/6: $F(1, 26) = 21.44, p = .000$ and O1/2: $F(1, 26) = 8.78, p = .006$. This result reflects the fact that the orthography effect in the 450-600 ms window was largest over the central, centro-parietal and temporal regions.
There was also a significant interaction between condition and hemisphere over the inner circle: $F(1, 26) = 4.46, p = .044$; middle circle: $F(1, 26) = 7.61, p = .011$ and outer circle: $F(1, 26) = 9.81, p = .004$. Over the left hemisphere, post-hoc analyses showed significant mean amplitude differences between the orthographically dissimilar and similar conditions in the inner circle: $F(1, 26) = 19.38, p = .000$; middle circle: $F(1, 26) = 24.65, p = .000$; and outer circle: $F(1, 26) = 18.96, p = .000$. Over the right hemisphere, post-hoc analyses revealed a significant orthography effect in the inner circle: $F(1, 26) = 11.22, p = .002$ and middle circle: $F(1, 26) = 7.12, p = .013$, but not in the outer circle.

This set of results reflects the fact that the orthography effect in the 450-600 ms window was largest over the left hemisphere.

In the 600-900 ms (late part of the LPC) temporal window, there was a significant main effect of condition over the midline: $F(1, 26) = 11.58, p = .002$; inner circle: $F(1, 26) = 5.66, p = .025$; and middle circle: $F(1, 26) = 4.93, p = .035$; and a trend toward a significant main effect of condition over the outer circle: $F(1, 26) = 3.08, p = .091$. This result indicates that in the 600-900 ms window post-target onset, the mean amplitude of the orthographically dissimilar condition (R–C+O– CHILD–COUGH) was less positive than the orthographically similar condition (R–C+O+ DOUGH–COUGH).

There was a trend toward a significant interaction between condition and electrode over the inner circle: $F(2, 52) = 2.69, p = .092$ and outer circle: $F(4, 104) = 2.97, p = .082$ and a significant interaction between condition and electrode over the middle circle: $F(3, 78) = 3.92, p = .039$. Further post-hoc tests showed that there was a (marginally) significant difference between the mean amplitudes elicited by the orthographically dissimilar and similar conditions at some of the middle circle sites: $F3/4: F(1, 26) = 3.1, p$
In addition to evaluating the mean amplitude differences for the orthography effect, there appeared to be a peak latency difference such that the orthographically dissimilar non-rhyming condition (e.g., R–C+O– CHILD–COUGH) peaked at about 400 ms post-target onset followed by the orthographically similar non-rhyming condition (e.g., R–C+O+ DOUGH–COUGH), which peaked at around 450 ms post-target onset. There was a significant main effect of condition over the inner circle: $F(1, 26) = 5.43, p = .028$; middle circle: $F(1, 26) = 5.05, p = .033$ and outer circle: $F(1, 26) = 9.5, p = .005$. This result reflects the fact that the effect of orthography produced two distinct negative peaks.

There was also a significant interaction in the peak latency analysis for the orthographically similar and dissimilar conditions and electrode site over the inner circle: $F(2, 52) = 5.87, p = .015$. Post-hoc tests showed a significant difference between the peak latencies of orthographically dissimilar and similar conditions at FC1/2: $F(1, 26) = 11.65, p = .002$ and C3/4: $F(1, 26) = 10.62, p = .003$. This result reflects the fact that the two peaks are more negative and peak slightly later over the fronto-central and central regions relative to the centro-parietal region of the inner circle.
Figure 12. Grand average event-related potentials elicited by non-rhyming consistency incongruent (solid lines) and consistency congruent conditions (dotted lines) from all 29 scalp electrodes. Data are plotted from 100 ms prior to the onset of the target word until 900 ms post-target onset, and negative is plotted up. The consistency effect is observed within the 0-100 ms and 350-450 ms temporal windows post-target onset.
Figure 13. Grand average event-related potentials elicited by non-rhyming orthographically dissimilar (solid lines) and orthographically similar conditions (dotted lines) from all 29 scalp electrodes. Data are plotted from 100 ms prior to the onset of the target word until 900 ms post-target onset, and negative is plotted up. The orthography effect is observed within the 280-420, 450-600 and 600-900 ms temporal windows post-target onset.
Discussion

Study 1 investigated the contributions of spelling-sound consistency and orthographic similarity to English monolinguals’ retrieval of phonology from orthography. Participants made rhyme judgments of semantically unrelated English word pairs presented sequentially in the visual modality, while behavioral responses and event-related potentials (ERPs) were recorded. The spelling-sound consistency and orthographic similarity of rhyming and non-rhyming prime-target pairs were varied systematically.

Rhyming Effect

Behavioral measures showed that rhyming targets elicited faster and more accurate responses than non-rhyming targets. These results are consistent with the findings of previous studies using the visual rhyme-priming paradigm with word stimuli (e.g., McPherson et al., 1998; Rugg, 1984a). Electrophysiological measures revealed that non-rhyming targets elicited more negative N400 and less positive LPC waveforms than rhyming targets in the 250-600 ms time window. The pattern of results observed over the N400 is consistent with findings reported in most previous ERP studies using the visual rhyme-priming paradigm with English letter, word and nonword stimuli (e.g., Coch, et al., 2011; Coch et al., 2008a, b; Grossi et al., 2001; Khateb et al., 2007; Rugg, 1984a, b; Weber-Fox et al., 2003).

The N400 effect in the rhyme-priming paradigm has been hypothesized to be a mismatch-related response that occurs when the phonological representation activated by the target word differs from that of the prime word (Khateb et al., 2007; Kramer & Donchin, 1987; Rugg, 1984a). According to the spreading activation account, a reduction of the N400 is noted in response to rhyming relative to non-rhyming conditions because
when participants access the phonological representation of the prime, the activation spreads automatically to phonologically related nodes, facilitating the processing of phonologically similar relative to phonologically dissimilar targets. The phonological representation of the prime that participants hold in working memory until the target is presented can map onto different rime spellings. These phonologically related spellings become automatically activated and produce facilitation for rhyme decisions when the target word contains one of the activated rimes. In other words, knowledge of both spelling-to-sound and sound-to-spelling mappings may be in use when rhyme judgments are made.

The LPC has been found in experimental tasks requiring judgments about stimuli, as is the case for rhyme judgment tasks (e.g., Praamstra, Meyer, & Levelt, 1994; Rugg, 1984a) and has been related to conscious recollection (e.g., Paller & Kutas, 1992; Smith, 1993). The LPC overlaps both temporally and spatially with the P600 component, being part of the same class of components, or perhaps representing the same component. The P600 has been reported to reflect sensitivity to syntactic violations (e.g., Frisch, Schlesewsky, Saddy, & Alpermann, 2002; Kaan, Harris, Gibson, & Holcomb, 2000), semantic violations (e.g., Van Herten, Kolk, & Chwilla, 2005) and spelling violations (e.g., Van de Meerendonk, Indefrey, Chwilla, & Kolk, 2011; Vissers, Chwilla, & Kolk, 2006). It has also been proposed that the P600 reflects monitoring of conflict generated from processing and reanalysis of information to resolve response uncertainty (e.g., Kolk & Chwilla, 2007). In the current study, the more positive LPC waveforms elicited in response to rhyming relative to non-rhyming word pairs may suggest increased response monitoring for rhyming conditions. This may suggest that although facilitated through
spreading activation to phonologically related nodes, rhyming decisions may require an increased degree of attention and control relative to non-rhyming decisions.

It should be noted that the design of the study was not optimal for investigating the RE given that a different set of targets was used in the rhyming conditions (i.e., consistent target words) than in the non-rhyming conditions (i.e., inconsistent target words). That is because the study was designed specifically to evaluate the effects of spelling-sound consistency and orthographic similarity on activating phonology from print.

**Consistency Effect**

Behavioral measures of response time showed facilitation for rhyming consistent target words primed by consistent (i.e., congruent in consistency to the target: R+C+O–WHITE–FIGHT) relative to inconsistent (i.e., incongruent in consistency to the target: R+C–O–HEIGHT–FIGHT) words. This finding was also supported by electrophysiological measures, which revealed that rhyming consistent target words elicited less negative N350 amplitudes in the 320-370 ms time window when primed by consistency congruent relative to consistency incongruent words. The N350 has been reported to correspond to the phonological analysis of orthographic word patterns (Bentin et al., 1999; Spironelli & Angrilli, 2007), suggesting that rhyme decisions involving a mismatch in spelling-sound consistency between prime-target word pairs may require more cognitive resources in the processing of phonology than rhyme decisions involving consistency congruent word pairs. The fact that the N350 amplitude is modulated by a mismatch in spelling-sound consistency may reflect participants’ processing of the neighborhood of friend to rival pronunciations activated by each prime. Primes with consistent spelling-sound mappings (e.g., WHITE) co-activate a rime neighborhood of
similarly pronounced words, known as *friends* (e.g., BITE, KITE, SITE, TRITE, WRITE). In contrast, primes with inconsistent mappings (e.g., HEIGHT) co-activate a rime neighborhood of *friend* (e.g., SLEIGHT) and *enemy* pronunciations (e.g., FREIGHT, WEIGHT). The co-activation of a rime neighborhood consisting of friends, as is the case for consistent primes (e.g., WHITE), facilitates the processing of phonologically similar consistent targets (e.g., FIGHT) because in consistency congruent rhyming trials there are no enemy pronunciations to be considered. For this reason, participants are fast in activating the only phonological representation available for the prime and are facilitated in recognizing the match in phonology with the consistent target, which also activates a single phonological representation. In contrast, the temporary activation of competing phonological representations associated with inconsistent primes (e.g., HEIGHT) slows down the retrieval of the phonological representation of the prime, which produces an overall delay in the recognition of the phonological match with the consistent target (e.g., FIGHT).

Behavioral measures of response accuracy showed facilitation for non-rhyming inconsistent target words primed by inconsistent (i.e., congruent in consistency to the target: R–C+O– CHILD–COUGH) relative to consistent (i.e., incongruent in consistency to the target: R–C–O– CHURCH–COUGH) words. Electrophysiological measures revealed that non-rhyming inconsistent target words elicited more negative N100 amplitudes in the 0-100 ms time window when primed by consistency incongruent relative to congruent words. However, the effect changed direction in the 350-450 ms temporal window such that non-rhyming inconsistent target words elicited more negative N400 amplitudes when primed by consistency congruent relative to consistency
incongruent words. The N100 has been shown to index lower level (feature-based) visual analysis, being involved in the early phase of letter identification (letter font and size; Chauncey, Holcomb, & Grainger, 2008; Rey, Dufau, Massol & Grainger, 2009). The fact that larger N100 amplitudes are elicited by conditions where the prime is consistent (R–C–O–CHURCH–COUGH) relative to conditions where the prime is inconsistent (R–C+O–CHILD–COUGH) may reflect early processing of orthography, such as the early stages of letter identification. Furthermore, the cost in processing consistency congruent relative to incongruent non-rhyming word pairs noted on the N400, a mismatch-related response (Kramer & Donchin, 1987), may be again related to the degree of consistency associated with the prime. Since consistent primes (e.g., CHURCH) activate a neighborhood of friend pronunciations and inconsistent primes (e.g., CHILD) activate a network of both friend and rival pronunciations, participants may gain access to the phonological representation of consistent primes faster relative to inconsistent primes. Furthermore, word pairs in which both primes and targets are inconsistent (R–C+O–CHILD–COUGH) may require more cognitive resources early in processing than word pairs in which the prime is consistent and the target is inconsistent (R–C–O–CHURCH–COUGH) because they activate more competing phonological representations. However, following this initial cost, the competition among the rival pronunciations of the inconsistent rimes (–ILD and –OUGH) found in the consistency congruent non-rhyming condition (R–C+O–CHILD–COUGH) facilitate the non-rhyming response because they yield the same decision. Thus, there may be a cognitive advantage to making a non-rhyming decision in response to two inconsistent words, just as there is an advantage to making a rhyming decision in response to two consistent words.
The effect of consistency found in English monolinguals brings further evidence that the N350 and N400 components index phonological processing (Bentin et al., 1999; Khateb et al., 2007; Kramer & Donchin, 1987; Rugg, 1984a; Ruz & Nobre, 2008; Spironelli & Angrilli, 2007) and provide a general measure of “stimulus mismatch” (e.g., Kramer & Donchin, 1987). Furthermore, it appears that English monolinguals are sensitive to the degree of consistency of prime-target word pairs, showing facilitation when both primes and targets are consistent (rhyming conditions) and inhibition when both primes and targets are inconsistent (non-rhyming conditions). Moreover, the fact that the consistency effect modulates the N400, which is primarily recognized as an index of lexical processing (e.g., Kutas & Hillyard, 1980; 1984), but no earlier components such as the P200 or N250, which have been associated with prelexical processes (e.g., Holcomb & Grainger, 2006; Martin, Kaine, & Kirby, 2006), may suggest that the competition between friend and rival pronunciations that English monolingual skilled readers experience in reading English words may be processed as an orthographic neighborhood of varying sizes (see Holcomb et al., 2002). The finding that English monolinguals show a small effect of consistency may bring further support to the flexible-unit-size hypothesis (e.g., Brown & Deavers, 1999; Perry & Ziegler, 2000), which argues that the choice of reading units may be flexible in deep orthographies such as English because English requires readers to actively use both small and large grain sizes to ensure that words are read correctly regardless of the consistency of their spelling-sound mappings. Because English monolinguals frequently alternate between consistent and inconsistent words in reading, the switch between consistent and inconsistent spelling-sound mappings may be less taxing to them than predicted. The
competition between friend and rival pronunciations occurs, but it may be short-lived in monolingual skilled readers of English.

**Orthography Effect**

Behavioral measures of response time and accuracy revealed facilitation for rhyming consistent target words primed by (consistency congruent) orthographically similar (e.g., R+C+O+ RIGHT–FIGHT) relative to orthographically dissimilar words (e.g., R+C+O–WHITE–FIGHT). This result replicates the findings of previous studies investigating the role of orthographic similarity in visual rhyme judgments (e.g., Kramer & Donchin, 1987; Polich et al., 1983; Rugg & Barrett, 1987; Weber-Fox et al., 2003). Electrophysiological measures revealed that rhyming targets primed by orthographically similar words elicited less negative N400 waveforms in the 200-410 ms temporal window than when primed by orthographically dissimilar words, suggesting facilitation for rhyming decisions involving orthographically similar prime-target pairs. In contrast, rhyming targets primed by orthographically similar words elicited less positive LPC waveforms in the 450-620 ms temporal window than when primed by orthographically dissimilar words, suggesting that rhyming decisions involve a conscious monitoring process before a correct response is made. This pattern of results is consistent with the findings of previous studies that manipulated the degree of orthographic overlap between primes and targets within rhyming conditions (e.g., Rugg & Barrett, 1987; Weber-Fox et al., 2003).

Rugg and Barrett (1987) reported that the phonological and orthographic similarity between prime-target word pairs form an additive effect that modulates the N450 component such that orthographically similar rhyming word pairs elicit less negative
N450 waveforms relative to orthographically dissimilar rhyming word pairs. In the current study, the phonological and orthographic similarity between prime-target word pairs is found to modulate the N400, an earlier component from the same class as N450. The facilitation for the orthographically similar relative to the orthographically dissimilar prime-target pairs comes in response to the orthographic match between the target and its prime. In the process of testing whether prime-target word pairs match in phonology, participants hold the phonological representation of the prime in working memory and compare it against the target. Since there may be a short time lag between the processing of the target’s orthography and the activation of its phonological representation (Grainger, Kiyonaga, & Holcomb, 2006), the less negative N400 waveform elicited by the orthographically similar condition suggests that participants recognize the mismatch between orthographic and phonological cues activated by the orthographically similar non-rhyming conditions.

The fact that the waveforms elicited by the rhyming targets primed by orthographically similar words were less positive in the LPC region than the waveforms elicited by the rhyming targets primed by orthographically dissimilar words suggests that more cognitive resources are needed in the reanalysis and monitoring of the orthographic and phonological cues associated with the orthographically dissimilar relative to the orthographically similar conditions. In other words, English monolinguals experience facilitation in making rhyming decisions for (consistency congruent) orthographically similar relative to orthographically dissimilar conditions.

Behavioral measures of response time and accuracy showed inhibition for non-rhyming inconsistent target words primed by (consistency congruent) orthographically
similar (R–C+O+ DOUGH–COUGH) relative to orthographically dissimilar words (e.g., R–C+O– CHILD–COUGH). This result replicates the findings of previous studies investigating the role of orthographic similarity in visual rhyme judgments (e.g., Kramer & Donchin, 1987; Polich et al., 1983; Rugg & Barrett, 1987; Weber-Fox et al., 2003). Electrophysiological measures revealed that non-rhyming targets primed by orthographically similar words elicited less negative N400 waveforms in the 280-420 ms temporal window than when primed by orthographically dissimilar words, suggesting orthographic interference during the early processing of orthographically similar prime-target word pairs. Furthermore, non-rhyming targets primed by orthographically similar words elicited more negative N450 waveforms in the 450-600 ms temporal window than when primed by orthographically dissimilar words, suggesting that the conflicting information resulting from processing orthographically similar word pairs that activate different phonological representations takes time to resolve. This suggests that, like in the rhyming conditions, participants initially compare the orthography of the target against the phonological representation of the prime stored in working memory. This comparison creates facilitation for the orthographically similar condition until the phonological representation of the target is activated, when inhibition for the orthographically similar condition is observed. This finding further confirms that the N400 component is modulated by phonological mismatch.

Furthermore, the fact that the waveforms elicited by the non-rhyming orthographically similar conditions were more positive relative to the waveforms elicited by the non-rhyming orthographically dissimilar conditions over the LPC may reflect the cognitive resources allocated to resolving the response uncertainty created by the
conflicting orthographic and phonological cues activated by the orthographically similar non-rhyming conditions. This suggests that participants closely monitor the conflicting cues and may reanalyze the information in order to produce a correct response.

The effect of orthography found in English monolinguals brings further evidence that converging orthographic and phonological cues produce facilitation in making rhyme decisions, whereas the divergent cues produce inhibition, causing participants to slow down and be more cautious with their responses. As reported in previous research studies (e.g., Rugg & Barrett, 1987), the N400 component is sensitive to the mismatch between orthographic and phonological information. Furthermore, the LPC is involved in the reanalysis of conflicting orthographic and phonological information, monitoring the accuracy of the behavioral responses.

In summary, English monolinguals’ rhyming decisions were facilitated by the consistency congruence of prime-target pairs, as well as converging cues from orthography and phonology. Furthermore, their non-rhyming decisions were facilitated by the consistency incongruence of prime-target pairs, but inhibited by diverging cues from orthography and phonology. These results suggest that cues from spelling-sound consistency may work both independently and concurrently with orthographic similarity cues in guiding readers’ mapping of print to sound. The effect of spelling-sound consistency is larger when it either converges or diverges from orthographic cues, than when it modulates processing in the absence of competing orthographic cues. This effect may be interpreted in light of the network of friends and enemies that mediate readers’ mapping of print to sound. It appears that the friends and enemies associated with a given rime have a stronger effect on a reader’s ability to activate the correct phonological
representation when they are overtly rather than covertly co-activated. That may be because prime-target word pairs chosen from the same rime neighborhood give the reader the initial impression that they belong or should be grouped together based on the processing of orthographic information relative to prime-target word pairs that come from different orthographic neighborhoods. This may be the case since orthographic information may be accessed slightly earlier than phonology (Grainger et al., 2006).

Alternatively, there may be an effect of spelling-sound consistency in processing primes and an effect of sound-to-spelling mapping in deciding whether targets rhyme with their primes. Activating the phonological representation of the prime entails the activation of a set of friend pronunciations if the prime is consistent and the activation of one set of friend and one set of rival pronunciations if the prime is inconsistent. As the correct phonological representation of the prime is held in working memory in order to be compared with the target for the purpose of deciding whether the two words rhyme, the rime spellings associated with the phonological representation activated by the prime (i.e., friend pronunciations) may receive a boost in activation. This may be a task-specific strategy through which participants build a set of hypotheses about the possible target rimes that would match in phonology with the prime. The hypothesized target rimes would involve the rime of the prime, which would have the highest level of activation, and other rimes that have friend pronunciations with the prime. When the target shares the rime of the prime, the initial facilitation that occurs across rhyming and non-rhyming conditions is due to the enhanced activation of the rime that is shared with the prime. This response strategy may not make a difference within either rhyming or non-rhyming conditions in the absence of orthographic overlap between primes and targets, but would
make a difference across such conditions, producing facilitation for rhyming relative to non-rhyming conditions.
Chapter 5

STUDY 2
The Role of Orthographic Depth in Modulating Bilinguals’ Sensitivity to L2 Consistency and Orthographic Similarity

Study 2 evaluated the role of bilinguals’ L1 orthographic depth in modulating their sensitivity to spelling-sound consistency and orthographic similarity in a deep L2 orthography (i.e., English). For this purpose, two bilingual groups (Spanish-English and Chinese-English) were tested on the same English rhyme judgment task used in Study 1, that systematically manipulated the spelling-sound consistency and orthographic similarity of prime-target word pairs. Spanish-English (Experiment 1) and Chinese-English (Experiment 2) bilinguals were chosen for this comparison because of the difference in their L1 orthographies. Spanish has a shallow alphabetic writing system with highly consistent spelling-sound mappings, which allow readers to adopt a small grain size reading strategy. In contrast, Chinese has a deep logographic writing system in which characters map onto whole syllables, recognized as whole units and thus can be considered to have a large grain size. Consequently, native speakers of Spanish and Chinese come to the task of reading with largely different expectations about how orthography maps to phonology. The aim of the current study was to investigate whether these two groups of non-native English readers transfer their L1 reading strategy to English (L2) when immersed in an L2 environment.

It was predicted that Spanish-English and Chinese-English bilinguals should evidence different sensitivity levels to English spelling-sound consistency and orthographic similarity if transfer of reading strategies from the L1 to the L2 occurs. Spanish-English
bilinguals should approach English reading with a small grain size, showing facilitation for consistent spelling-sound mappings and orthographic similarity in the presence of converging phonological cues. In contrast, Chinese-English bilinguals are expected to use a large grain size when reading English words, experiencing reduced sensitivity to consistency and orthographic similarity. However, if both Spanish-English and Chinese-English bilingual groups have adopted an English reading strategy, then they may resemble the English monolingual control group, providing evidence against granularity transfer. In contrast, if the two bilingual groups differ from the monolingual group in similar ways, then results may simply reflect general strategy differences in lower-proficiency readers. Furthermore, the rhyming effect typically found in the ERP literature (e.g., Chen et al., 2010; Grossi et al., 2001; Weber-Fox et al., 2003) is expected to be replicated in this study, with both Spanish-English and Chinese-English bilingual participants demonstrating increased negative amplitudes peaking at around 350-450 ms post-stimulus in response to non-rhyming versus rhyming targets.

**Experiment 1: Spanish-English Bilinguals**

**Method**

**Participants**

Results are presented for 20 native speakers of Spanish (9 male; mean age = 24.2 years; age range = 18 to 31 years), who were students at the Pennsylvania State University. All participants were right-handed, had normal or corrected-to-normal vision, and no history of neurological dysfunction, language or reading disorders. All were volunteers paid $30 for participating in two experimental sessions.
A total of 32 participants initially completed the study, but data from 12 participants were excluded from the final analysis. Data from five participants were excluded due to an insufficient number of trials: Trials were lost due to excess muscle artifact (primarily from blinks) for four of these participants, whereas for one other participant trials were lost due to technical difficulties during data collection. Two other participants were excluded for having switched language dominance to English. In addition, five participants were excluded for achieving lower than 60% response accuracy on the overall rhyming or non-rhyming conditions. Participants who did not meet this accuracy level were excluded from the analysis because having less than 20 correct, artifact-free responses per condition added noise to the data.

The final set of participants had achieved high levels of English proficiency, but had maintained dominance in their native language (i.e., Spanish), which was their primary language of instruction in school through eighth grade. Participants had no consistent exposure to English before age of 6. Using a 7-point rating system, participants rated their English proficiency as averaging 6.1 (SD 0.66).

**Stimuli and Procedure**

Participants completed two individual testing sessions: an EEG session, followed by a behavioral session scheduled no more than two weeks apart. Study 2 used the same stimuli (see page 73 for a review of the stimuli and conditions) and experimental paradigm (see page 60 for a review of the sequence of events used in the English rhyme judgment task) as Study 1. It should be noted that bilingual participants completed a different (28-item) language history questionnaire than English monolinguals (all the questionnaire items can be found in Appendix B).
Spanish-English bilinguals (Study 2) completed the same word identification task as English monolinguals in Study 1, with the exception that bilingual participants were asked not only to cross off any of the words that were unknown to them, but also to read out loud all the words on the list. Their responses were audio recorded and later coded for accuracy.

Like English monolinguals (Study 1), Spanish-English bilinguals (Study 2 Experiment 1) were administered a battery of behavioral measures during the second testing session to assess their phonological working memory, reading skills, language proficiency and individual difference in cognitive resources. The difference was that English monolinguals were only assessed in English, while Spanish-English bilinguals were assessed in the first language (i.e., Spanish) when phonological working memory and individual differences in cognitive resources were measured, and in both their first (i.e., Spanish) and second language (i.e., English) when their reading abilities and language proficiency were measured. More specifically, bilinguals’ phonological working memory was measured using a Spanish translation of the Memory for Digits subtest of the Comprehensive Test of Phonological Processing (CTOPP, Wagner et al., 1999) and their individual differences in cognitive resources were measured using a Spanish translation of the operation span task used in Study 1. Furthermore, participants’ Spanish reading fluency was assessed with the Spanish version of the Sight Word Reading subtest of the TOWRE (SpanWRE, Miller, Heilmann, Nockerts, Iglesias, Fabiano, & Francis, 2006). To measure untimed Spanish reading accuracy, the equivalent Word Identification and Word Attack subtests of the Pruebas de Aprovechamiento-Revisada (Woodcock, Muñoz-Sandoval, McGrew, Mather, 2004) were used. Two
measures of English (L2) reading ability were used: (1) The Sight Word Reading and Phonemic Decoding subtests of the Test of Word Reading Efficiency (TOWRE, Torgesen et al., 1999) were used to measure the number of words and pseudowords that are read correctly in 45 seconds. (2) The Word Identification and the Word Attack subtests of the Woodcock Reading Mastery Tests – Revised (Woodcock, 1987) were used to measure the untimed reading accuracy of words and pseudowords, respectively. Moreover, two picture-naming tasks, the first requiring participants to name line drawings in their L1 (i.e., Spanish) and the second in English (L2) were used to assess language proficiency and dominance.

**EEG Recording Procedure**

Study 2 used the electrode setup and recoding procedure described on page 61.

**Data Analysis**

Study 2 used the same data analysis strategy as Study 1 (see page 75 for a review), with the exception of the task performance inclusion criteria, which required participants to have produced at least 20 correct, artifact-free responses per condition (with the exception of the non-rhyming condition that manipulated orthography, e.g., DOUGH – COUGH, which was too difficult for some participants) and to have at least 60 percent overall accuracy in the rhyming and non-rhyming conditions in order to be included in the analyses. A subset of 10 participants (4 male; mean age = 23.1 years; age range = 19 to 31 years), who had produced at least 20 correct, artifact-free responses in the non-rhyming condition containing the orthographic similarity manipulation (e.g., DOUGH – COUGH), was used in the analyses for this condition. These inclusion criteria differ from the ones used in Study 1 (at least 70 percent response accuracy across rhyming and non-
rhyming trials and at least 70 percent artifact-free correct response trials within each of the six conditions) because the participants tested in Study 2 were performing the task in their second language (i.e., English), which involved a greater degree of difficulty relative to performing the task in one’s native language, as was the case for the participants tested in Study 1 (i.e., English monolinguals).

The mean amplitude of the rhyming effect was calculated in the 250-800 ms time window post-target onset. In addition, smaller temporal windows were chosen based on visual observation of the grand averages to evaluate the effects of the consistency and orthographic similarity manipulations that were unique to the current sets of studies. Specifically, the mean amplitude of the spelling-sound consistency effect was evaluated for four windows within the rhyming conditions (0-150 ms, 200-300 ms, 300-500 ms and 550-900 ms) and three windows within the non-rhyming conditions (230-290 ms, 350-450 ms and 500-900 ms). Furthermore, the mean amplitude of the orthographic similarity effect was evaluated for three windows within the rhyming conditions (0-150 ms, 200-300 ms and 300-500 ms) and three windows in the non-rhyming conditions (150-300 ms, 300-450 ms and 450-700 ms).
Results

Behavioral Results

The behavioral results are shown in Figures 14 and 15. In a comparison of responses to all rhyming and all non-rhyming conditions, there was a significant main effect of condition on response times: $F(1, 19) = 10.89, p = .004$ and accuracy: $F(1, 19) = 12.97, p = .002$, indicating that Spanish-English bilinguals were faster and more accurate in responding to rhyming relative to non-rhyming conditions.

Rhyming conditions. There was no effect of prime consistency on rhyming response times, but there was a significant main effect of prime consistency on response accuracy: $F(1, 19) = 40.2, p = .000$, indicating that Spanish-English bilinguals were more accurate in responding to rhyming consistent target words when primed by consistent (e.g., R+C+O– WHITE–FIGHT) relative to inconsistent words (e.g., R+C–O– HEIGHT–FIGHT) with limited orthographic similarity to the target.

There was also a significant effect of prime-target orthographic similarity on rhyming response times: $F(1, 19) = 50.35, p = .000$ and accuracy: $F(1, 19) = 63.16, p = .000$, indicating that Spanish-English bilinguals were faster and more accurate in responding to rhyming targets primed by words with high (e.g., R+C+O+ RIGHT–FIGHT) rather than low (e.g., R+C+O– WHITE–FIGHT) degrees of orthographic similarity to the target. Recall that when prime-target orthographic similarity was varied, spelling-sound consistency was held constant.

Non-rhyming conditions. There was a significant effect of prime consistency on non-rhyming response times: $F(1, 19) = 13.66, p = .002$ and a trend toward significance on accuracy: $F(1, 19) = 3.41, p = .081$. These results reflect the fact that Spanish-English
bilinguals were faster and relatively more accurate in responding to non-rhyming inconsistent target words when primed by consistent (e.g., R–C–O– CHURCH–COUGH) relative to inconsistent (e.g., R–C+O– CHILD–COUGH) words with limited orthographic similarity to the target.

Furthermore, there was a significant effect of prime-target orthographic similarity on non-rhyming response times: $F(1, 19) = 24.28, p = .000$ and accuracy: $F(1, 19) = 209.22, p = .000$, indicating that Spanish-English bilingual participants were slower and less accurate in responding to non-rhyming targets primed by orthographically similar (R–C+O+ DOUGH–COUGH) than dissimilar words (e.g., R–C+O– CHILD–COUGH). Recall that when prime-target orthographic similarity was varied, spelling-sound consistency was held constant.

![Figure 14](image)

*Figure 14.* Mean reaction times (in ms) for rhyming and non-rhyming conditions. Error bars show 95% confidence intervals.
Electrophysiological Results

The waveforms elicited during the task showed a series of peaks consistent with previous visual word recognition studies. Specifically, there was a clear negative peak around 100 ms (N100), followed by a positive peak around 200 ms (P200), a negative peak between 200-300 ms (N250) and 300-500 ms (N400) and a late positive component between 550-900 ms (LPC). Differences between the waveforms for the critical conditions are described below.

**Rhyming effect (RE).** Figure 16 shows the ERP waveforms elicited by all rhyming and non-rhyming conditions (forming the rhyming effect) at all 29 scalp electrode sites. This comparison is most similar to those presented in other studies evaluating the rhyming effect (RE). As in the past literature, the RE was most notable as a mean amplitude difference between the conditions such that the non-rhyming condition elicited
a more negative waveform compared to the rhyming condition within the 250-800 ms time window. The difference between rhyming and non-rhyming targets was biggest at about 400 ms post-target onset.

Between 250 and 800 ms, there was a significant main effect of condition for each set of electrode sites: midline: $F(1, 19) = 39.98, p = .000$; inner circle: $F(1, 19) = 37.86, p = .000$; middle circle: $F(1, 19) = 30.02, p = .002$; and outer circle: $F(1, 19) = 22.50, p = .000$. The result reflects the fact that the mean amplitude of the non-rhyming targets was more negative than the mean amplitude of the rhyming targets in the 250-800 ms window post-target onset.

There was also a significant interaction between condition and electrode over the midline: $F(4, 76) = 5.76, p = .007$. There was a significant difference in the mean amplitude of rhyming and non-rhyming conditions at each electrode of the midline: FPz: $F(1, 19) = 17.88, p = .000$; Fz: $F(1, 19) = 20.39, p = .000$; Cz: $F(1, 19) = 33.51, p = .000$; Pz: $F(1, 19) = 46.99, p = .000$; and Oz: $F(1, 19) = 27.84, p = .000$. However, the effect (i.e., the difference between the two conditions) was smaller over the frontal sites and largest over the central and parietal sites of the midline.

There was also a significant interaction between condition and electrode over the inner circle: $F(2, 38) = 5.65, p = .018$ and middle circle: $F(3, 57) = 10.01, p = .001$. There was a significant difference in the mean amplitude of rhyming and non-rhyming conditions at each electrode of the inner circle: FC1/2: $F(1, 19) = 26.18, p = .000$; C3/4: $F(1, 19) = 34.71, p = .000$; CP1/2: $F(1, 19) = 47.95, p = .000$; and middle circle: F3/4: $F(1, 19) = 16.31, p = .001$; FC5/6: $F(1, 19) = 10.53, p = .004$; CP5/6: $F(1, 19) = 38.77, p = .000$; P3/4: $F(1, 19) = 38.48, p = .000$. However, the interaction is likely driven by the
fact that the rhyming effect was largest over the centro-parietal regions of inner circle and over the centro-parietal and parietal regions of the middle circle.

Furthermore, there was a significant interaction among condition, electrode and hemisphere over the outer circle sites: $F(4, 76) = 5.28, p = .012$. Further 2 (experimental condition) X 5 (electrode) ANOVAs were performed to investigate the three-way interaction over each hemisphere at the middle circle sites. Over the left hemisphere, there was a main effect of condition: $F(1, 19) = 16.37, p = .001$. Further paired t-tests revealed significant differences between rhyming and non-rhyming conditions at FP1: $t(19) = 3.58, p = .01$; T5: $t(19) = 4.52, p = .000$ and O1: $t(19) = 5.15, p = .000$. There was no rhyming effect at the F7 and T3 electrode sites. Over the right hemisphere, there was a main effect of condition: $F(1, 19) = 15.39, p = .001$. Further paired t-tests showed a trend toward a significant difference between rhyming and non-rhyming conditions at F8: $t(19) = 2.78, p = .06$ and a significant difference between rhyming and non-rhyming conditions at all other electrode sites over the right hemisphere of the outer circle except FP2: T4: $t(19) = 3.38, p = .015$; T6: $t(19) = 4.44, p = .000$ and O2: $t(19) = 3.33, p = .02$. This result reflects that a larger rhyming effect was elicited over the right hemisphere frontal and occipital sites of the outer circle.

**Rhyming conditions.**

**Consistency effect.** Figure 17 shows the waveforms elicited by rhyming consistent target words primed by inconsistent versus consistent words (forming the consistency effect) at all 29 scalp electrode sites. The consistency effect was notable as a subtle mean amplitude difference between the rhyming conditions such that the consistent target words elicited a more negative waveform when primed by consistent relative to
inconsistent words in the 0-150 ms time window, which produced a negative peak at around 100 ms (N100); in the 200-300 ms time window, which produced a negative peak at around 250 ms (N250); and in the 300-500 ms time window, which produced a negative peak at around 400 ms (N400). Furthermore, consistent target words elicited a less positive waveform when primed by consistent relative to inconsistent words in the 550-900 ms time window, which peaked at around 600 ms (LPC).

In the 0-150 ms (N100) time window, there was a trend toward a significant main effect of condition over the midline: $F(1, 19) = 3.67, p = .070$; inner circle: $F(1, 19) = 4.06, p = .058$; and middle circle: $F(1, 19) = 3.17, p = .091$. The result reflects the fact that consistent targets primed by consistent words (e.g., R+C+O– WHITE–FIGHT) elicited more negative amplitudes relative to targets primed by inconsistent words (e.g., R+C–O– HEIGHT–FIGHT) in the 0-150 ms time window. There was also a significant interaction between condition and hemisphere over the inner circle: $F(1, 19) = 8.63, p = .008$ and a trend toward a significant interaction over the middle circle: $F(1, 19) = 3.96, p = .061$. Post-hoc tests showed an effect of condition over the left hemisphere of the inner circle: $F(1, 19) = 5.50, p = .030$. This result reflects the fact that the consistency effect was larger over the left hemisphere of the inner circle in the 0-150 ms time window.

In the 200-300 ms (N250) time window, there was a significant interaction between condition and hemisphere over the inner circle: $F(1, 19) = 6.29, p = .021$. Post-hoc tests showed an effect of condition that did not reach significance over either hemisphere. However, the interaction appears to be driven by the left hemisphere, where consistent targets primed by consistent words (e.g., R+C+O– WHITE–FIGHT) elicited more
negative amplitudes relative to targets primed by inconsistent words (e.g., R+C–O–HEIGHT–FIGHT) in the 200-300 ms time window.

In the 300-500 ms (N400) time window, there was a significant interaction between condition and hemisphere over the inner circle: $F(1, 19) = 17.85, p = .000$; middle circle: $F(1, 19) = 12.20, p = .002$ and outer circle: $F(1, 19) = 7.01, p = .016$. Post-hoc tests showed a main effect of condition that did not reach significance over either hemisphere of the inner circle, but that showed a trend toward significance over the left hemisphere of the middle circle: $F(1, 19) = 3.30, p = .085$ and outer circle: $F(1, 19) = 3.25, p = .087$. This effect indicates that in the 300-500 ms time window, consistency congruent trials (e.g., R+C+O–WHITE–FIGHT) elicited more negative amplitudes relative to consistency incongruent trials (e.g., R+C–O–HEIGHT–FIGHT) over the left hemisphere of the middle and outer circles. The same pattern of results was observed over the left hemisphere of the inner circle, even though the effect did not reach significance.

In the 550-900 ms (LPC) time window, there was a significant main effect of condition over the midline: $F(1, 19) = 5.22, p = .034$; inner circle: $F(1, 19) = 6.90, p = .017$; and middle circle: $F(1, 19) = 5.56, p = .029$. The result reflects the fact that in the 550-900 ms time window, consistent targets primed by consistent words (e.g., R+C+O–WHITE–FIGHT) elicited less positive amplitudes relative to targets primed by inconsistent words (e.g., R+C–O–HEIGHT–FIGHT). Furthermore, there was a significant interaction between condition and hemisphere over the inner circle: $F(1, 19) = 5.44, p = .031$ and middle circle: $F(1, 19) = 5.13, p = .035$. Post-hoc tests showed a significant main effect of condition over the left hemisphere of the inner circle: $F(1, 19) = 9.57, p = .006$ and middle circle: $F(1, 19) = 11.57, p = .003$. There was also a trend
toward a significant difference over the right hemisphere of the inner circle: \( F(1, 19) = 3.85, p = .065 \). This set of results reflects the fact that the consistency effect elicited in the 550-900 ms time window was larger over the left hemisphere for the inner and middle electrode sites.

**Orthography effect.** Figure 18 shows the waveforms elicited by rhyming consistent target words primed by orthographically dissimilar relative to orthographically similar consistent words (forming the orthography effect) at all 29 scalp electrode sites. This comparison is similar to those presented in other studies evaluating the effect of orthographic similarity on rhyme judgments (e.g., Rugg & Barrett, 1987; Weber-Fox et al., 2003). The orthography effect was notable as a mean amplitude difference between rhyming conditions such that the orthographically similar word pairs elicited less negative waveforms compared to the orthographically dissimilar word pairs in the 0-150 ms time window, which produced a negative peak at around 100 ms (N100), in the 200-300 ms time window, which produced a negative peak at around 250 ms (N250) and in the 300-500 ms time window, which produced a negative peak at around 400 ms (N400) post-target onset.

In the 0-150 ms (N100) time window, there was a significant main effect of condition over the midline: \( F(1, 19) = 5.02, p = .037 \) and a trend toward a significant difference over the inner circle: \( F(1, 19) = 4.14, p = .056 \); and middle circle: \( F(1, 19) = 3.80, p = .066 \). These results confirm the observation that orthographically dissimilar rhyming word pairs (e.g., R+C+O– WHITE–FIGHT) elicited more negative amplitudes than orthographically similar rhyming word pairs (e.g., R+C+O+ RIGHT–FIGHT) in the 0-150 ms time window. There was also a trend toward a significant interaction between
condition and hemisphere over the inner circle: \( F(1, 19) = 3.48, p = .078 \). This trend appeared to reflect that fact that the orthography effect was larger over the left relative to the right hemisphere of the inner circle. Furthermore, there was a trend toward a significant interaction between condition and electrode over the middle circle: \( F(1, 19) = 2.98, p = .079 \). This trend appeared to reflect the fact that the effect was slightly larger over the parietal region.

In the 200-300 ms (N250) time window, there was a significant main effect of condition over the midline: \( F(1, 19) = 4.55, p = .046 \) and a trend toward a significant main effect over the outer circle: \( F(1, 19) = 3.12, p = .093 \). This set of results reflects the fact that the orthographically dissimilar rhyming word pairs (e.g., R+C+O– WHITE–FIGHT) elicited a larger N250 amplitude relative to orthographically similar rhyming word pairs (e.g., R+C+O+ RIGHT–FIGHT) over the midline and outer circle sites.

In the 300-500 ms (N400) time window, there was a significant main effect of condition for each set of electrode sites: midline: \( F(1, 19) = 19.38, p = .000 \); inner circle: \( F(1, 19) = 24.75, p = .000 \); middle circle: \( F(1, 19) = 19.85, p = .000 \); and outer circle: \( F(1, 19) = 11.09, p = .004 \). This set of results reflects the fact that the orthographically dissimilar rhyming word pairs (e.g., R+C+O– WHITE–FIGHT) elicited a larger N400 amplitude relative to orthographically similar rhyming word pairs (e.g., R+C+O+ RIGHT–FIGHT). There was also a significant interaction between condition and electrode over the midline: \( F(4, 76) = 5.20, p = .016 \) and a trend toward a significant interaction between condition and electrode over the middle circle: \( F(3, 57) = 3.29, p = .072 \). Further post-hoc tests to follow up on the midline interaction showed that there was a significant difference in the mean amplitude of the orthographically similar versus
dissimilar word pairs at Fz: $F(1, 19) = 9.07, p = .035$; Cz: $F(1, 19) = 20.60, p = .000$; Pz: $F(1, 19) = 32.45, p = .000$; and Oz: $F(1, 19) = 10.36, p = .025$. These results reflect that fact that the mean amplitude difference between the orthographically similar and dissimilar conditions was largest over the central and parietal electrode sites. The same pattern of results was noted over the middle circle, even though the results did not reach significance. Furthermore, there was a significant interaction between condition and hemisphere over the inner circle: $F(1, 19) = 4.64, p = .044$ and a trend toward a significant interaction between condition and hemisphere over the middle circle: $F(1, 19) = 3.99, p = .060$. Post-hoc tests to follow up on this result over both left and right hemispheres of the inner circle showed a significant difference over both the left hemisphere: $F(1, 19) = 26.76, p = .000$ and right hemisphere: $F(1, 19) = 19.05, p = .000$. This result appeared to reflect the fact that the orthography effect was smaller over the right hemisphere. The same pattern of results was observed over the middle circle, even through the interaction failed to reach significance.
Figure 16. Grand average event-related potentials elicited by rhyming conditions (solid lines) and non-rhyming conditions (dotted lines) from all 29 scalp electrodes. Data are plotted from 100 ms prior to the onset of the target word until 900 ms post-target onset, and negative is plotted up. The RE effect is observed within the 250-800 ms window post-target onset.
Figure 17. Grand average event-related potentials elicited by rhyming consistency incongruent (solid lines) and consistency congruent conditions (dotted lines) from all 29 scalp electrodes. Data are plotted from 100 ms prior to the onset of the target word until 900 ms post-target onset, and negative is plotted up. The consistency effect is observed within the 0-150 ms, 200-300 ms, 300-500 ms and 550-900 ms time windows post-target onset.
Figure 18. Grand average event-related potentials elicited by rhyming orthographically dissimilar (solid lines) and orthographically similar conditions (dotted lines) from all 29 scalp electrodes. Data are plotted from 100 ms prior to the onset of the target word until 900 ms post-target onset, and negative is plotted up. The orthography effect is observed within the 0-150 ms and 200-550 ms time windows post-target onset.
Non-rhyming conditions.

Consistency effect. Figure 19 shows the waveforms elicited by non-rhyming inconsistent target words primed by consistent versus inconsistent words (forming the consistency effect) at all 29 scalp electrode sites. The consistency effect was notable as a subtle mean amplitude difference between the non-rhyming conditions such that the inconsistent target words elicited a more negative waveform when primed by consistent relative to inconsistent words in the 230-290 ms time window, which produced a negative peak at around 250 ms post-target onset (N250) and in the 350-450 ms time window, which produced a negative peak at about 400 ms post-target onset (N400). Additionally, inconsistent target words elicited a less positive waveform when primed by consistent relative to inconsistent words in the 500-900 ms time window, which produced a positive peak at about 600 ms post-target onset (LPC).

In the 230-290 ms (N250) time window, there was a significant main effect of condition over the inner circle: \( F(1, 19) = 4.96, p = .038 \) and a trend toward a significant main effect of condition over the midline: \( F(1, 19) = 3.90, p = .063 \). These results reflect the fact that the consistency incongruent non-rhyming conditions (e.g., R–C–O–CHURCH–COUGH) elicited more negative amplitudes relative to consistency congruent non-rhyming conditions (e.g., R–C+O–CHILD–COUGH) over the midline and inner circle in the 230-290 ms time window. There was also a trend toward a significant interaction between condition and electrode over the inner circle: \( F(2, 38) = 2.97, p = .096 \) and middle circle: \( F(3, 57) = 2.91, p = .087 \). This trend appeared to reflect the fact that the consistency effect within the 230-290 ms time window was largest over the frontal and smallest over the centro-parietal and parietal sites.
In the 350-450 ms (N400) time window, there was a significant interaction among condition, electrode and hemisphere over the middle circle: \( F(3, 57) = 5.31, p = .009 \). Further 2 (experimental condition) X 4 (electrode) ANOVAs were performed to investigate the three-way interaction over each hemisphere at the middle circle sites. The effect showed a trend toward a significant main effect of condition over the left hemisphere: \( F(1, 19) = 4.29, p = .052 \), but no significant difference over the right hemisphere. These results reflect the fact that the consistency incongruent non-rhyming conditions (e.g., R–C–O– CHURCH–COUGH) may elicit more negative amplitudes relative to consistency congruent non-rhyming conditions (e.g., R–C+O– CHILD–COUGH), particularly over the left hemisphere.

In the 500-900 ms (LPC) time window, there was a significant interaction between condition and electrode over the outer circle: \( F(4, 76) = 4.87, p = .016 \) and a trend toward a significant interaction between condition and electrode over the midline: \( F(4, 76) = 2.56, p = .091 \) and middle circle: \( F(3, 57) = 3.44, p = .060 \). Further post-hoc tests to follow up on the outer circle interaction showed that there was a significant difference in the mean amplitude of the consistency congruent versus incongruent word pairs at FP1/2: \( F(1, 19) = 4.80, p = .041 \). This result reflects that the difference in mean amplitude between the consistency congruent and incongruent conditions (the less positive waveform generated by the consistency incongruent relative to the congruent condition) had a frontal distribution over the outer circle. The same pattern is observed over the midline, even though the interaction did not reach significance.

There was also a significant interaction between condition and hemisphere over the inner circle: \( F(1, 19) = 5.91, p = .025 \) and a trend toward a significant interaction between
condition and hemisphere over the middle circle: \( F(1, 19) = 3.58, p = .074 \). Post-hoc tests to follow up on this result over both left and right hemispheres of the inner circle did not reach significance. Nonetheless, the pattern of results reflects a left hemisphere distribution of the effect over both inner and middle circles.

**Orthography effect.** Figure 20 shows the waveforms elicited by non-rhyming inconsistent target words primed by orthographically dissimilar versus orthographically similar inconsistent words (forming the orthography effect) at all 29 scalp electrode sites. A subset of 10 Spanish-English bilingual participants, who performed this condition with most accuracy were included in this analysis. That is because performance on this condition appeared to be modulated by English (L2) proficiency. This comparison is similar to those presented in other studies evaluating the effect of orthographic similarity on non-rhyme judgments (e.g., Rugg & Barrett, 1987; Weber-Fox et al., 2003). The orthography effect was notable as a mean amplitude difference between non-rhyming conditions such that the orthographically similar word pairs elicited less positive waveforms compared to the orthographically dissimilar word pairs in the 150-300 ms time window, which produced a positive peak at around 200 ms post-target onset (P200). Furthermore, the orthographically dissimilar word pairs elicited more negative waveform compared to the orthographically similar word pairs in the 300-450 ms time window, which produced a negative peak at around 400 ms post-target onset (N400). Additionally, the orthographically dissimilar condition produced a more positive waveform in the 450-700 ms time window, which produced a positive peak at about 600 ms post-target onset (LPC).
In the 150-300 ms (P200) time window, there was a significant interaction between condition and electrode over the midline: $F(4, 36) = 4.12, p = .044$; middle circle: $F(3, 27) = 4.80, p = .036$; and outer circle: $F(4, 36) = 4.11, p = .041$. Further post-hoc tests showed that there was a trend toward a significant difference in the mean amplitude of the orthographically similar versus dissimilar non-rhyming pairs over the following electrode sites of the midline: $Fz: F(1, 9) = 4.79, p = .056$; Oz: $F(1, 9) = 4.10, p = .074$; and a significant difference in the mean amplitude of the orthographically similar versus dissimilar non-rhyming pairs over the following electrode sites of the middle circle: $F3/4: F(1, 9) = 5.25, p = .048$; and outer circle: O1/2: $F(1, 9) = 5.32, p = .047$. The orthographically similar non-rhyming condition (R–C+O+ DOUGH–COUGH) elicited less positive amplitudes relative to the orthographically dissimilar non-rhyming condition (e.g., R–C+O– CHILD–COUGH) over the frontal electrode sites, yet the reverse effect was noticed over the occipital electrode sites. There was also a significant interaction between condition and hemisphere over the outer circle: $F(1, 9) = 7.25, p = .025$ and a trend toward a significant interaction between condition and hemisphere over the middle circle: $F(1, 9) = 4.49, p = .063$. The difference between orthographically similar and dissimilar non-rhyming conditions did not reach significance over either hemisphere of the outer circle. However, the pattern of results suggests that the orthographically similar non-rhyming condition (R–C+O+ DOUGH–COUGH) elicited less positive amplitudes relative to the orthographically dissimilar non-rhyming condition (e.g., R–C+O– CHILD–COUGH) over the left hemisphere of the middle circle, but more positive amplitudes relative to the orthographically dissimilar non-rhyming condition (e.g., R–C+O– CHILD–COUGH) over the right hemisphere of the outer circle.
In the 300-450 ms (N400) time window, there was a significant interaction between condition and hemisphere over the inner circle: $F(1, 9) = 5.15, p = .049$; middle circle: $F(1, 9) = 13.21, p = .005$ and outer circle: $F(1, 9) = 17.81, p = .002$. The difference between orthographically similar and dissimilar non-rhyming conditions did not approach significance over either hemisphere of the inner and middle circles, but it was significant over the right hemisphere of the outer circle: $F(1, 9) = 8.70, p = .016$. This set of results reflects the fact that the orthographically dissimilar non-rhyming condition (e.g., R–C+O– CHILD–COUGH) elicited more negative amplitudes relative to the orthographically similar non-rhyming condition (R–C+O+ DOUGH–COUGH) over the right hemisphere of the outer circle in the 300-450 ms time window. A right hemisphere distribution of the effect was also seen over the inner and middle circles, even though the results did not reach significance. There was also a trend toward a significant interaction between condition and electrode over the middle circle: $F(3, 27) = 2.58, p = .086$.

Furthermore, there was a trend toward a significant main effect of condition over the outer circle: $F(1, 9) = 3.39, p = .099$.

In the 450-700 ms (LPC) time window, there was a significant main effect of condition over the midline: $F(1, 9) = 8.70, p = .016$; inner circle: $F(1, 9) = 13.63, p = .005$ and middle circle: $F(1, 9) = 11.62, p = .008$. This result reflected the fact that the orthographically similar non-rhyming condition (R–C+O+ DOUGH–COUGH) elicited less positive amplitudes relative to the orthographically dissimilar non-rhyming condition (e.g., R–C+O– CHILD–COUGH) in the 450-700 ms window post-target onset. There was also a significant interaction between condition and electrode over the midline: $F(1, 9) = 4.83, p = .033$. Further post-hoc tests showed that there was a trend toward a
significant difference in the mean amplitude of the orthographically similar versus dissimilar non-rhyming conditions at FPz: $F(1, 9) = 3.41, p = .098$ and a significant difference over the following electrode sites: $Fz: F(1, 9) = 14.41, p = .004$; $Cz: F(1, 9) = 12.31, p = .007$; and $Pz: F(1, 9) = 5.49, p = .044$. The result suggests that the mean amplitude of the orthography effect was smaller over the parietal and occipital sites relative to the frontal and central sites of the midline.
Figure 19. Grand average event-related potentials elicited by non-rhyming consistency incongruent (solid lines) and consistency congruent conditions (dotted lines) from all 29 scalp electrodes. Data are plotted from 100 ms prior to the onset of the target word until 900 ms post-target onset, and negative is plotted up. The consistency effect is observed within the 350-450 ms and 500-900 ms time windows post-target onset.
Figure 20. Grand average event-related potentials elicited by non-rhyming orthographically dissimilar (solid lines) and orthographically similar conditions (dotted lines) from all 29 scalp electrodes. Data are plotted from 100 ms prior to the onset of the target word until 900 ms post-target onset, and negative is plotted up. The orthography effect is observed within the 150-300 ms, 300-450 ms, 450-700 ms and 750-900 ms time windows post-target onset.
Discussion

Experiment 1 of Study 2 sought evidence that bilinguals with an orthographically shallow first language (L1 – Spanish) transferred reading strategies to their orthographically deep second language (L2 – English). Spanish-English bilinguals who were immersed in an English-speaking environment (the US) made rhyme judgments of semantically unrelated English word pairs presented sequentially in the visual modality, while behavioral responses and event-related potentials (ERPs) were recorded. The spelling-sound consistency and orthographic similarity of rhyming and non-rhyming prime-target pairs were varied systematically.

Rhyming Effect

Behavioral measures showed that rhyming targets elicited faster and more accurate responses than non-rhyming targets. These results are consistent with the performance of English monolinguals in Study 1 and with the findings of previous studies using the visual rhyme-priming paradigm with word stimuli with both monolinguals and bilinguals (e.g., Chen et al., 2010; McPherson et al., 1998; Rugg, 1984a). Electrophysiological measures revealed that non-rhyming targets elicited more negative N400 and less positive LPC waveforms than rhyming targets in the 250-800 ms time window. The pattern of results observed over the N400 was predicted and is consistent with the results found for English monolinguals in Study 1. Furthermore, this pattern of results replicates the findings from a previous study in which Chinese-English bilinguals made rhyme judgment decisions involving English (L2) word pairs (Chen et al., 2010), providing further evidence that bilinguals’ phonological processing in the L2 is similar to monolinguals’ phonological processing of their native language. The effect is also
consistent with findings reported in most previous ERP studies using the visual rhyme-priming paradigm with letter, word and nonword stimuli in English (L1; e.g., Coch, et al., 2011; Coch et al., 2008a, b; Grossi et al., 2001; Khateb et al., 2007; Rugg, 1984a, b; Weber-Fox et al., 2003), Spanish (L1) word pairs (Perez-Abalo et al., 1994) and Chinese (L1) word pairs (Chen et al., 2010).

The N400 effect in the rhyme-priming paradigm has been hypothesized to be a mismatch-related response that occurs when the phonological representation activated by the target word differs from that of the prime word (Khateb et al., 2007; Kramer & Donchin, 1987; Rugg, 1984a). According to the spreading activation account, a reduction of the N400 is noted in response to rhyming relative to non-rhyming conditions because when participants access the phonological representation of the prime, the activation spreads automatically to phonologically related nodes, facilitating the processing of phonologically similar relative to phonologically dissimilar targets.

The more positive LPC elicited in response to rhyming relative to non-rhyming conditions may reflect increased response monitoring for the rhyming relative to the non-rhyming conditions. The same pattern of results was noted in English monolinguals. However, the LPC elicited by Spanish-English bilinguals may be related to the attention and monitoring processes involved in making rhyme judgments in the second language.

It should be noted that the design of the study was not optimal for investigating the RE given that a different set of targets was used in the rhyming conditions (i.e., consistent target words) than in the non-rhyming conditions (i.e., inconsistent target words). That is because the study was designed specifically to evaluate the effects of spelling-sound consistency and orthographic similarity on activating phonology from print.
**Consistency Effect**

Behavioral measures of response accuracy showed facilitation for rhyming consistent target words primed by consistent (i.e., congruent in consistency to the target: R+C+O—WHITE—FIGHT) relative to inconsistent (i.e., incongruent in consistency to the target: R+C−O—HEIGHT—FIGHT) words. In contrast, electrophysiological measures revealed that rhyming consistent targets primed by consistent words (e.g., R+C+O—WHITE—FIGHT) elicited more negative N100 (0-150 ms), N250 (200-300 ms) and N400 (300-500 ms) waveforms than when primed by inconsistent words (e.g., R+C−O—HEIGHT—FIGHT). Furthermore, the consistency congruent conditions (e.g., R+C+O—WHITE—FIGHT) also elicited less positive LPC (550-900 ms) waveforms relative to the consistency incongruent conditions (e.g., R+C−O—HEIGHT—FIGHT). These mean amplitude differences evidenced throughout the ERP epoch may suggest a spillover effect from the processing of the prime. Since Spanish-English bilinguals are making rhyme judgments in their second language, they are slower than English monolinguals in processing the phonological representation of the prime and of the subsequent target, so their processing of consistency gets dragged throughout the epoch.

As noted in the previous chapter, the N100 is an index of feature-based visual analysis (e.g., letter font and size; Chauncey et al., 2008; Rey et al., 2009). Rey and colleagues (2009) have reported that individual letter identification takes places within the 100-200 ms time window. The authors describe the pattern of letter recognition to involve an N100 and a P200. Although the P200 does not reach significance, the same pattern of results is seen in the current study, suggesting that Spanish-English bilinguals may be more likely to rely on individual letter recognition in the early stages of
processing consistency congruent relative to incongruent rhyming conditions. This may indicate the initial phase of a sub-lexical reading strategy.

The N250 component, typically identified in masked priming studies (e.g., Chauncey et al., 2008; Grainger et al., 2006), has been interpreted as being sensitive to processing at the interface between sub-lexical and lexical representations (Duñabeitia, Molinaro, Laka, Estévez, & Carreiras, 2009; Grainger & Holcomb, 2010). It has been reported as being involved in the processing of ordered letter combinations (e.g., bigrams, trigrams), which are used to generate both sub-lexical and whole word phonological representations (Holcomb & Grainger, 2006). However, other studies have related the N250 component to sub-lexical processing (Grainger et al., 2006). It has been suggested that the early part of the N250 (200-250 ms) may reflect prelexical orthographic processing, whereas the late part (250-300 ms) may reflect prelexical phonological processing (Morris, Grainger, & Holcomb, 2008). The fact that Spanish-English bilinguals produce an N250 component in a task in which both primes and targets are each presented for 350 ms suggests that this presentation rate may be somewhat fast for L2 visual word recognition. Furthermore, the finding that larger N250 amplitudes were elicited by consistent relative to inconsistent primes paired with consistent targets may suggest that Spanish-English bilinguals used a small grain size in reading consistency congruent (e.g., R+C+O– WHITE–FIGHT) relative to incongruent (e.g., R+C–O– HEIGHT–FIGHT) word pairs. That may be because the presentation of a consistent prime facilitates the use of a small grain size in reading the target. Readers of a shallow L1 orthography, as is the case of Spanish-English bilinguals, are most skilled in using a small grain size, as they may transfer this reading strategy from their L1. However, the use of a small grain size requires an assembly
process, which may be more cognitively taxing than the use of a whole word approach, which is primed by the consistency incongruent conditions. Alternatively, it may be that the presentation of a consistent prime in a rhyming condition (e.g., WHITE) causes bilinguals with a shallow L1 orthography to expect that the target share the spelling of the rime (e.g. KITE) in order to rhyme with the prime. That is because in languages with shallow orthographies, such as Spanish, two words do not rhyme unless they share the spelling of the rime or of the last syllable.

The fact that consistency congruent word pairs (e.g., R+C+O– WHITE–FIGHT) elicited more negative N400 waveforms relative to consistency incongruent word pairs (e.g., R+C–O– HEIGHT–FIGHT) may suggest that Spanish-English bilinguals are sensitive to the neighborhood of friend pronunciations activated by both primes and targets in the consistency congruent condition. This interpretation is consistent with the findings of Holcomb and colleagues (2002), who reported that words and pseudowords with many lexical neighbors generated larger N400s than similar items with fewer lexical neighbors, whereas a facilitation effect was observed in the behavioral results. However, further analysis of the orthographic neighborhood size of the two rhyming conditions compared here is needed to further establish the validity of this interpretation.

Furthermore, the fact that the consistency incongruent word pairs (e.g., R+C–O– HEIGHT–FIGHT) elicited more positive LPC waveforms relative to consistency congruent word pairs (e.g., R+C+O– WHITE–FIGHT) suggests that Spanish-English bilinguals re-analyze the consistency mismatch encountered in the consistency incongruent conditions before making a rhyming decision. The facilitation for the
consistency congruent conditions observed over the LPC carries through to the accuracy of responses for the consistency congruent relative to incongruent rhyming conditions.

Behavioral measures of reaction time and accuracy showed facilitation for non-rhyming inconsistent target words primed by consistent (consistency incongruent: R–C–O– CHURCH–COUGH) relative to inconsistent (consistency congruent: R–C+O– CHILD–COUGH) words. Electrophysiological measures revealed that consistent primes paired with inconsistent targets (e.g., R–C–O– CHURCH–COUGH) elicited more negative N250 (230-290 ms) and N400 (350-450 ms) waveforms relative to inconsistent primes paired with inconsistent targets (e.g., R–C+O– CHILD–COUGH), but less positive LPC (500-900 ms) waveforms.

The fact that non-rhyming inconsistent targets elicited more negative N250 amplitudes when primed by consistent relative to inconsistent words suggests once again that Spanish-English bilinguals have employed a small grain size in response to consistent primes. The mean amplitude difference between the consistency congruent (e.g., R–C+O– CHILD–COUGH) and incongruent (e.g., R–C–O– CHURCH–COUGH) non-rhyming conditions over the N250 may have captured the cost of switching from the small grain size used in reading the consistent primes (e.g., CHURCH) to a large grain size needed in reading the inconsistent targets (e.g., COUGH) relative to the non-rhyming conditions in which both primes and targets had inconsistent spelling-sound mappings (e.g., R–C+O– CHILD–COUGH). Alternatively, the N250 may have captured bilinguals’ slow speed of processing in a second language. To them, the presentation of the prime and target for 350 ms each might have been somewhat similar to monolinguals’ experience on a masked priming task.
Furthermore, the larger N400 mean amplitude noted for the consistency incongruent (e.g., R–C–O– CHURCH–COUGH) relative to the congruent (e.g., R–C+O– CHILD–COUGH) non-rhyming conditions suggests once again that the N400 may be modulated by the size of the orthographic neighborhood (e.g., Holcomb et al., 2002). In this case, the number of friend pronunciations associated with the consistent prime might modulate the mean amplitude of the N400. Alternatively, the N400 might respond to the mismatch in spelling-sound consistency between primes and targets.

The more positive LPC mean amplitude elicited by inconsistent targets when paired with inconsistent (e.g., R–C+O– CHILD–COUGH) relative to consistent (e.g., R–C–O– CHURCH–COUGH) primes may suggest that Spanish-English bilinguals employ more cognitive resources to resolve the response uncertainty generated by prime-target word pairs in which both words are inconsistent relative to consistent primes that are paired with inconsistent targets. The results pattern revealed by the LPC is similar to the one found in the behavioral data, suggesting that Spanish-English bilinguals maintain their preference for spelling-sound consistency in a deep L2 orthography.

Throughout their processing of rhyming and non-rhyming conditions, Spanish-English bilinguals show a preference for spelling-sound consistency. This is consistent with the prediction that readers of a shallow L1 orthography would transfer the expectation of spelling-sound consistency from their L1 to the L2 even though the orthographic depth of the L2 may differ from that of the L1. It may also be that the mind searches for regularities in input in order to improve processing speed. In the case of readers of a shallow L1 orthography, regularity and consistency are made more salient within spelling-sound mappings, making the preference for consistency more obvious
than in readers of less transparent orthographies, such as Chinese (e.g., Fang et al., 1986; Hue, 1992; Lee et al., 2005, 2010).

**Orthography Effect**

Behavioral measures of response time and accuracy revealed facilitation for rhyming consistent target words primed by (consistency congruent) orthographically similar (e.g., R+C+O+ RIGHT–FIGHT) relative to orthographically dissimilar words (e.g., R+C+O–WHITE–FIGHT). This result is consistent with the findings of Study 1 and replicates the findings of previous studies investigating the role of orthographic similarity in visual rhyme judgments (e.g., Kramer & Donchin, 1987; Polich et al., 1983; Rugg & Barrett, 1987; Weber-Fox et al., 2003). Electrophysiological measures brought further evidence for the facilitation argument by revealing that rhyming consistent targets elicited more negative N100 (0-150 ms), N250 (200-300 ms) and N400 (300-500 ms) mean amplitudes when primed by orthographically dissimilar relative to similar consistent words. The modulation of the N400 component is consistent with the findings of previous studies that manipulated the degree of orthographic overlap between primes and targets within rhyming conditions (e.g., Rugg & Barrett, 1987; Weber-Fox et al., 2003).

As noted earlier, the N100 may be involved in the early stages of letter identification (Rey et al., 2009). The fact that it is modulated by the orthography manipulation, being followed by an N250, which has been reported as being involved in the processing of letter combinations (Holcomb & Grainger, 2006), suggests that Spanish-English bilinguals use a small grain size in response to the consistency of the experimental items used in the two consistency congruent rhyming conditions compared here. This observation is further supported by the pattern of the N250 effect, which elicited more
negative amplitudes for the orthographically dissimilar relative to the orthographically similar consistent word pairs. This pattern of results is consistent with the findings reported by Holcomb and Grainger (2006), who found that the N250 is sensitive to the degree of prime-target orthographic overlap, being larger for targets with limited relative to complete orthographic overlap to the prime.

The fact that the orthographically similar rhyming word pairs elicited less negative N400 amplitudes relative to orthographically dissimilar rhyming word pairs brings further evidence that the phonological and orthographic similarity between prime-target word pairs forms an additive effect that modulates the N400. This orthography effect noted over the N400 component is consistent with the effect reported in Study 1 and with the N450 component described by Rugg and Barrett (1987). The fact that the Spanish-English bilinguals do not appear to closely monitor the converging orthographic and phonological information in making rhyme decisions suggests that Spanish-English bilinguals transfer an expectation of shared phonology (i.e. spelling-sound consistency) in response to prime-target orthographic similarity from their shallow L1 orthography.

Behavioral measures of response time and accuracy showed inhibition for non-rhyming inconsistent target words primed by (consistency congruent) orthographically similar (R–C+O+ DOUGH–COUGH) relative to orthographically dissimilar words (e.g., R–C+O– CHILD–COUGH). This result is consistent with the findings reported in Study 1 and replicates the findings of previous studies investigating the role of orthographic similarity in visual rhyme judgments (e.g., Kramer & Donchin, 1987; Polich et al., 1983; Rugg & Barrett, 1987; Weber-Fox et al., 2003). Electrophysiological measures revealed that orthographically similar non-rhyming conditions elicited less positive P200 (150-300
(300-450 ms) amplitudes and less positive LPC (450-700 ms) amplitudes relative to the orthographically dissimilar conditions.

The P200 component, also known as “recognition potential”, has been suggested to index an early stage of lexical access (Martin-Loeches, Hinojosa, Gomez-Jarabo, & Rubia, 1999). Martin and colleagues (2006) have argued that smaller P200 amplitudes elicited for irregular words may reflect a heavy reliance on a large grain size during reading, whereas a more positive P200 amplitude may suggest reliance on a small grain size (e.g., Hsu, Tsai, Lee, & Tzeng, 2009; Lee et al., 2007). Furthermore, Barnea and Breznitz (1998) found that a smaller P200 was elicited by non-rhyming relative to rhyming word pairs. Moreover, a smaller P200 component has also been associated with orthographically similar relative to dissimilar word pairs in phonological judgments tasks (e.g., Liu, Perfetti, & Hart, 2003). The fact that a less positive P200 waveform was elicited in response to orthographically similar relative to dissimilar word pairs is consistent with the pattern of results reported by Liu and colleagues (2003) and may suggest that the Spanish-English bilinguals may have employed a large grain size in reading the orthographically similar inconsistent word pairs. This result may bring further support to the interpretation of the P200 component as being an early marker of lexical access.

The more negative N400 waveform elicited by the orthographically dissimilar relative to the orthographically similar conditions may suggest that the N400 is modulated by the mismatch in phonological and orthographic cues. Alternatively, the difference noted on the N400 may be related differential lexical access between the inconsistent item pairs as
a function of their degree of orthographic similarity. It may be that the orthographically similar word pairs have a smaller lexical neighborhood relative to the orthographically dissimilar word pairs.

The more positive LPC waveforms elicited in the processing of orthographically dissimilar relative to similar non-rhyming word pairs may reflect that Spanish-English bilinguals devote more resources to monitor the response to the orthographically dissimilar relative to similar non-rhyming word pairs. This may suggest that the expectation of spelling-sound consistency that is inherent to Spanish-English bilinguals’ L1 orthography (i.e., Spanish) is strongly activated by the orthographically similar relative to the orthographically dissimilar non-rhyming conditions, given that a degree of orthographic overlap between word pairs needed to produce a rhyme in Spanish may be larger or more salient than it is in English (L2). Therefore, Spanish-English bilinguals appear to have difficulty in inhibiting this expectation of phonological similarity in the presence of orthographic overlap in an inconsistent L2 orthography.

Throughout their processing of rhyming and non-rhyming conditions, Spanish-English bilinguals were facilitated by orthographic similarity in making rhyming decisions, but inhibited in making non-rhyme decisions. This pattern of results is overall similar to that produced by English monolinguals. However, Spanish-English bilinguals appeared more likely than English monolinguals to interpret orthographic similarity as an indicator of spelling-sound consistency. More specifically, the distinct ERP pattern of results found across English monolinguals and Spanish-English bilinguals in the non-rhyming conditions may have to do with the influence of bilinguals’ shallow L1 orthography, which produces a facilitation effect in response to orthographic similarity
regardless of divergent cues from phonology. A common underlying factor for this facilitation may be the initial processing of the target orthography before the phonological representation is activated.

Spanish-English bilinguals’ overall sensitivity to consistent spelling-sound mappings in a deep L2 orthography provides support to the argument that L1 orthographic depth modulates bilinguals’ expectation of spelling-sound consistency in the L2. Unlike English monolinguals, who show evidence of grain size flexibility, L1-dominant Spanish-English bilinguals appear to prefer using a small grain size when reading a deep orthography, such as that of English. This finding is consistent with the results reported by Botezatu et al. (in preparation), who found that L1-dominant Spanish-English bilinguals showed a larger cost for naming English irregular and inconsistent words relative to regular and consistent words than L2-dominant Spanish-English bilinguals. The current study provides further support to the argument made by Botezatu et al. that L1-dominant Spanish-English bilinguals transfer reading strategies from a shallow L1 orthography to a deep L2 orthography.

The findings of the current experiment are inconsistent with the results reported by Meschyan and Hernandez (2006) and Pitts and Hanley (2010), who have shown that Spanish-English bilinguals were more likely to use a large rather than a small grain size when reading English words. Their findings suggest that Spanish-English bilinguals adapt their reading strategy in response to the orthographic depth of their L2 and that they may develop a flexible grain size across their two languages. Bilinguals’ language dominance and overall English proficiency may account for this difference in results. Meschyan and Hernandez (2006) characterize their participants and English-dominant
and having early exposure to English, whereas Pitts and Hanley (2010) characterize their participants as proficient, but varying in immersion experience, duration and type of instruction. Therefore, it may be that the reading strategy bilinguals adopt in response to the orthographic depth of their L2 is modulated by language dominance, with the dominance switchers being more likely to use a large grain size in reading English than the non-switchers (see Botezatu et al., in preparation).
Experiment 2: Chinese-English Bilinguals

Method

Participants

Results are presented for 20 native speakers of Chinese (2 male; mean age = 21.4 years; age range = 18 to 26 years), who were students at the Pennsylvania State University. All participants were right-handed, had normal or corrected-to-normal vision, and no history of neurological dysfunction, language or reading disorders. All were volunteers paid $30 for participating in two experimental sessions.

A total of 31 participants had initially completed the study, but data from 11 participants were excluded from the final analysis. Data from four participants were excluded due to an insufficient number of trials: Trials were lost due to excess muscle artifact (primarily from blinks) for two of these participants, whereas for the other two participants, trials were lost due to technical difficulties during data collection. One other participant was excluded for being ambidextrous. In addition, six participants were excluded for achieving lower than 60% response accuracy on the overall rhyming or non-rhyming conditions.

Participants had achieved high levels of English proficiency, but had maintained dominance in their native language (i.e., Chinese), which was their primary language of instruction in school through eighth grade. Participants had no consistent exposure to English before age of 6. Using a 7-point rating system, native Chinese speakers who were included in the final analysis rated their English skills as averaging 5.38 (SD 0.51). It is important to note that self-ratings are subjective, being modulated by cultural differences, so although the self-ratings of this group were lower than those for the Spanish-English
bilinguals in Study 2, Experiment 1, these groups are likely comparable due to their similar language-learning histories.

Stimuli and Procedure

Experiment 2 used the same stimuli and procedure as Experiment 1 of Study 2 (see page 71 for a review), with the difference that the assessment of participants’ phonological working memory, L1 reading skills, L1 language proficiency and individual difference in cognitive resources were administered in Chinese. Chinese (Mandarin) reading ability was assessed with a timed reading speed test and an untimed reading accuracy test developed for the current study (T. Guo, personal communication, May 18, 2010), each composed of 92 Chinese nouns increasing in difficulty and matched on frequency, number of syllables, and number of strokes. The Chinese reading tests were developed to be similar to the Spanish version of the Sight Word Reading subtest of the TOWRE (SpanWRE, Miller et al., 2006) and the Word Identification subtest of the Pruebas de Aprovechamiento-Revisada (Woodcock et al., 2004) used in Experiment 1 of Study 2.

EEG Recording Procedure and Data Analysis

Experiment 2 used the same electrode setup, recoding procedure and data analysis strategy as Experiment 1 and Study 1 (see pages 61, 65 and 75 for a review). As in Experiment 1, a subset of 10 participants (1 male; mean age = 22 years; age range = 20 to 26 years), who had produced at least 20 correct, artifact-free responses in the non-rhyming condition containing the orthographic similarity manipulation (e.g., DOUGH – COUGH), was used in the analyses for this condition.

The mean amplitude of the rhyming effect was calculated in the 250-700 ms window
post-target onset. In addition, smaller temporal windows were chosen based on visual observation of the grand averages to evaluate the effects of the consistency and orthographic similarity manipulations that were unique to the current sets of studies. Specifically, the mean amplitude of the spelling-sound consistency effect was evaluated for five windows in the rhyming conditions (0-150 ms, 150-300 ms, 300-450 ms, 450-600 ms and 600-900 ms) and two windows in the non-rhyming conditions (170-300 ms, 300-450 ms and 450-700 ms). Furthermore, the mean amplitude of orthographic similarity effect was evaluated for four windows within the rhyming conditions (0-150 ms, 150-300 ms, 300-500 ms and 500-700 ms) and two windows in the non-rhyming conditions (250-450 ms and 600-750 ms).
Results

Behavioral Results

The behavioral results are shown in Figures 21 and 22. In a comparison of responses to all rhyming and all non-rhyming conditions, there was no effect of condition on response times, but there was a significant main effect of condition on response accuracy: $F(1, 19) = 18.06, p = .000$. This result reflects the fact that Chinese-English bilinguals were equally fast in responding to rhyming and non-rhyming conditions, but more accurate in responding to rhyming relative to non-rhyming conditions.

**Rhyming conditions.** There was no effect of prime consistency on rhyming response times or accuracy, indicating that Chinese-English bilinguals were equally fast and accurate in responding to rhyming consistent target words when primed by either inconsistent (e.g., R+C–O– HEIGHT–FIGHT) or consistent words (e.g., R+C+O– WHITE–FIGHT) with limited orthographic similarity to the target.

There was also a significant effect of orthographic similarity on rhyming response times: $F(1, 19) = 34.24, p = .000$ and accuracy: $F(1, 19) = 50.98, p = .000$, indicating that Chinese-English bilinguals were faster and more accurate in responding to rhyming targets primed by words with high (e.g., R+C+O+ RIGHT–FIGHT) rather than low (e.g., R+C+O– WHITE–FIGHT) degrees of orthographic similarity to the target. Recall that when prime-target orthographic similarity was varied, spelling-sound consistency was held constant.

**Non-rhyming conditions.** There was a significant effect of prime consistency on non-rhyming response times: $F(1, 19) = 6.51, p = .019$, indicating that Chinese-English bilinguals were faster in responding to non-rhyming inconsistent target words when
primed by consistent (e.g., R–C–O– CHURCH–COUGH) relative to inconsistent (e.g., R–C+O– CHILD–COUGH) words with limited orthographic similarity to the target. However, participants were equally accurate in responding to non-rhyming inconsistent target words regardless of whether primed by consistent or inconsistent words.

Furthermore, there was a significant effect of prime-target orthographic similarity on non-rhyming response times: $F(1, 19) = 13.25, p = .002$ and accuracy: $F(1, 19) = 153, p = .000$, indicating that Chinese-English bilinguals were slower and less accurate in responding to non-rhyming targets primed by orthographically similar (R–C+O+ DOUGH–COUGH) than dissimilar words (e.g., R–C+O– CHILD–COUGH). Recall that when prime-target orthographic similarity was varied, spelling-sound consistency was held constant.

Figure 21. Mean reaction times (in ms) for rhyming and non-rhyming conditions. Error bars show 95% confidence intervals.
Figure 22. Mean accuracy rates (in percentages) for rhyming and non-rhyming conditions. Error bars show 95% confidence intervals.

Electrophysiological Results

The waveforms elicited during the task showed a series of peaks consistent with previous visual word recognition studies. Specifically, there was a clear negative peak around 100 ms (N100), followed by a positive peak around 200 ms (P200), a negative peak between 300-500 ms (N400) and a late positive component between 600-900 ms (LPC). Differences between the waveforms for the critical conditions are described below.

Rhyming effect (RE). Figure 23 shows the ERP waveforms elicited by all rhyming and non-rhyming conditions (forming the rhyming effect) at all 29 scalp electrode sites. This comparison is most similar to those presented in other studies evaluating the rhyming effect (RE). As in the past literature, the RE was most notable as a mean
amplitude difference between the conditions such that the non-rhyming condition elicited a larger negative waveform compared to the rhyming condition. The difference between rhyming and non-rhyming targets was biggest at about 400 ms post-target onset.

Between 250 and 700 ms, there was a significant main effect of condition for each set of electrode sites: midline: $F(1, 19) = 17.95, p = .000$; inner circle: $F(1, 19) = 17.54, p = .000$; middle circle: $F(1, 19) = 13.4, p = .002$; and outer circle: $F(1, 19) = 13.04, p = .002$. The result reflects the fact that the mean amplitude of the non-rhyming targets was more negative than the mean amplitude of the rhyming targets in the 250-700 ms window post-target onset. There was also a trend toward a significant interaction between condition and electrode over the midline: $F(4, 76) = 3.34, p = .050$. Furthermore, there was a trend toward a significant interaction among condition, electrode and hemisphere over the middle circle: $F(3, 57) = 2.41, p = .096$.

**Rhyming conditions.**

*Consistency effect.* Figure 24 shows the waveforms elicited by rhyming consistent target words primed by inconsistent versus consistent words (forming the consistency effect) at all 29 scalp electrode sites. The consistency effect was notable as a mean amplitude difference between the rhyming conditions such that the consistent target words elicited more negative waveforms when primed by inconsistent relative to consistent words in the 0-150 ms time window, which produced a negative peak at around 100 ms post-target (N100). Furthermore, consistent target words elicited less positive waveforms when primed by inconsistent relative to consistent words in the 150-300 ms time window, which produced a positive peak at about 200 ms post-target onset (P200). Additionally, consistent targets elicited more negative waveforms when primed
by inconsistent relative to consistent words in the 300-450 ms time window, producing a
negative peak at about 400 ms post-target onset (early N400) and in the 450-600 ms time
window, producing a negative peak at about 500 ms post-target onset (late N400). Lastly,
consistent targets elicited more positive waveforms relative to inconsistent targets in the
600-900 ms time window, which produced a positive peak at about 600 ms post-target
onset (LPC).

In the 0-150 ms (N100) time window, there was a significant main effect of condition
over the midline: $F(1, 19) = 12.17, p = .002$; inner circle: $F(1, 19) = 12.38, p = .002$; and
middle circle: $F(1, 19) = 7.14, p = .015$ and a trend toward a significant main effect of
condition over the outer circle: $F(1, 19) = 4.06, p = .058$. The result reflects the fact that
consistent targets primed by inconsistent words (e.g., R+C–O– HEIGHT–FIGHT)
elicited more negative amplitudes relative to targets primed by consistent words (e.g.,
R+C+O– WHITE–FIGHT).

Furthermore, in the 0-150 ms time window, there was a significant interaction
between condition and electrode over the midline: $F(4, 76) = 3.73, p = .036$. Further post-
hoc tests showed that there was a significant difference between the mean amplitudes
elicited by the consistency congruent and incongruent rhyming conditions at Fz: $F(1, 19)
= 6.77, p = .018$; Cz: $F(1, 19) = 15.01, p = .001$; Pz: $F(1, 19) = 14.8, p = .001$ and Oz:
$F(1, 19) = 11.1, p = .003$. Although the effect was significant at all midline sites, the
interaction was likely driven by the fact that the difference between conditions was of the
smallest magnitude over the pre-frontal region.

From 0-150 ms there was also a significant interaction between condition and
hemisphere over the inner circle: $F(1, 19) = 4.44, p = .049$. Post-hoc tests showed a main
effect of condition over the left hemisphere: \( F(1, 19) = 10.66, p = .004 \), as well as over the right hemisphere: \( F(1, 19) = 12.68, p = .002 \). However, the effect was slightly larger over the right hemisphere of the inner circle as compared to the left hemisphere.

Moreover, in this window (0-150 ms) there was a significant interaction among condition, electrode and hemisphere over the middle circle: \( F(3, 57) = 3.74, p = .027 \). Further 2 (experimental condition) X 4 (electrode) ANOVAs were performed to investigate the three-way interaction over each hemisphere at the middle circle sites. Over the left hemisphere, there was a main effect of condition that showed a trend toward significance: \( F(1, 19) = 3.05, p = .097 \). Over the right hemisphere, there was a significant main effect of condition: \( F(1, 19) = 9.35, p = .006 \). Paired t-tests for the right hemisphere sites showed a significant difference between the mean amplitudes elicited by the consistency congruent and incongruent conditions at CP6: \( t(19) = -2.99, p = .028 \) and P4: \( t(19) = -3.81, p = .004 \). This set of results indicates that the consistency effect found in the 0-150 ms time window had a centro-parietal distribution over the right hemisphere of the middle circle. There was also a trend toward a significant interaction among condition, electrode and hemisphere over the outer circle: \( F(4, 76) = 2.89, p = .056 \).

In the 150-300 ms (P200) time window, there was a significant main effect of condition over the midline: \( F(1, 19) = 6.04, p = .024 \); inner circle: \( F(1, 19) = 6.04, p = .024 \); and middle circle: \( F(1, 19) = 4.51, p = .047 \) and a trend toward a significant main effect of condition over the outer circle: \( F(1, 19) = 3.32, p = .084 \). The result reflects the fact that consistent targets primed by inconsistent words (e.g., R+C–O– HEIGHT–FIGHT) elicited less positive amplitudes relative to targets primed by consistent words (e.g., R+C+O– WHITE–FIGHT).
Between 150 and 300 ms there was also a significant interaction between condition and electrode at the following sets of electrode sites: midline: $F(4, 76) = 4.76, p = .021$; inner circle: $F(2, 38) = 8.06, p = .005$ and outer circle: $F(4, 76) = 4.05, p = .044$. Further post-hoc tests showed that there was a significant difference between the mean amplitudes elicited by the consistency congruent and incongruent rhyming conditions over the following midline electrode sites: Cz: $F(1, 19) = 5.99, p = .024$; Pz: $F(1, 19) = 16.37, p = .001$; Oz: $F(1, 19) = 17.44, p = .001$; inner circle electrodes sites: C3/4: $F(1, 19) = 6.05, p = .024$; CP1/2: $F(1, 19) = 12.31, p = .002$; and outer circle electrode sites: T5/6: $F(1, 19) = 11.65, p = .003$ and O1/2: $F(1, 19) = 12.98, p = .002$. This set of results reflects the fact that in the 150-300 ms time window, the consistency effect was smaller over the frontal regions compared to the rest of the head.

Furthermore, from 150-300 ms, there was a significant interaction between condition and hemisphere over the inner circle: $F(1, 19) = 11.24, p = .003$ and outer circle: $F(1, 19) = 20.01, p = .000$. Over the inner circle, there was a trend toward a significant difference over the left hemisphere: $F(1, 19) = 3.26, p = .087$ and a significant effect over the right hemisphere: $F(1, 19) = 9.12, p = .007$. Over the outer circle, the effect was only significant over the right hemisphere: $F(1, 19) = 10.9, p = .004$. These results reflect the fact that the consistency effect had a right hemisphere distribution over the inner and outer electrode sites in the 150-300 ms time window.

From 150-300 ms there was also a significant interaction among condition, electrode and hemisphere over the middle circle: $F(3, 57) = 5.99, p = .003$. Further 2 (experimental condition) X 4 (electrode) ANOVAs were performed to investigate the three-way interaction over each hemisphere at the middle circle sites. The effect was significant
over the right hemisphere: $F(1, 19) = 10.23, p = .005$. Further paired t-tests showed significant differences between consistency congruent and incongruent rhyming conditions at CP6: $t(19) = -4.34, p = .000$ and P4: $t(19) = -5.24, p = .000$. These results indicate that the consistency effect was largest over the centro-parietal and parietal sites of the middle circle in the 150-300 ms time window.

In the 300-450 ms (early N400) time window, there was a significant main effect of condition for each set of electrode sites: midline: $F(1, 19) = 6.92, p = .016$; inner circle: $F(1, 19) = 5.11, p = .036$; middle circle: $F(1, 19) = 5.63, p = .028$ and outer circle: $F(1, 19) = 8.12, p = .01$. The result reflects the fact that consistent targets primed by inconsistent words (e.g., R+C–O–HEIGHT–FIGHT) elicited more negative amplitudes relative to targets primed by consistent words (e.g., R+C+O–WHITE–FIGHT).

There was also a trend toward a significant interaction between condition and electrode over the inner circle: $F(2, 38) = 3.5, p = .063$ and a significant interaction over the middle circle: $F(3, 57) = 3.97, p = .046$. Further post-hoc tests showed that there was a significant difference between the mean amplitudes elicited by the consistency congruent and incongruent rhyming conditions over the middle circle at CP5/6: $F(1, 19) = 7.49, p = .013$ and P3/4: $F(1, 19) = 10.77, p = .004$. These results reflect the fact that the consistency effect continued to have a centro-parietal distribution over the middle circle in the 300-450 ms time window.

Furthermore, between 300 and 450 ms, there was a significant interaction between condition and hemisphere over the inner circle: $F(1, 19) = 7.45, p = .013$; middle circle: $F(1, 19) = 10.74, p = .004$ and outer circle: $F(1, 19) = 8.04, p = .011$. The effect showed a trend toward significance over the left hemisphere of the inner circle: $F(1, 19) = 3.38, p = \ldots$
and was insignificant over the left hemisphere of the middle and outer circles. Over the right hemisphere, the effect was significant over the inner circle: $F(1, 19) = 6.94, p = .016$; middle circle: $F(1, 19) = 9.65, p = .006$ and outer circle: $F(1, 19) = 12.16, p = .002$. This set of results reflects the fact that the consistency effect was larger over the right relative to the left hemisphere.

In the 450-600 ms (late N400) time window, there was a significant main effect of condition over the outer circle: $F(1, 19) = 5.04, p = .037$. The result reflects the fact that in the 450-600 ms time window consistent targets primed by inconsistent words (e.g., R+C–O– HEIGHT–FIGHT) elicited more negative amplitudes relative to targets primed by consistent words (e.g., R+C+O– WHITE–FIGHT) over the outer circle.

From 450-600 ms there was also a significant interaction between condition and hemisphere over the inner circle: $F(1, 19) = 8.7, p = .008$ and outer circle: $F(1, 19) = 6.08, p = .023$. The effect was insignificant over the left hemisphere of the inner and outer circles, but showed a trend toward a significant difference over the right hemisphere of the inner circle: $F(1, 19) = 3.5, p = .077$ and was significant over the right hemisphere of the outer circle: $F(1, 19) = 7.83, p = .01$. These results reflect the fact that the consistency effect in the 450-600 ms time window had a right hemisphere distribution over the inner and outer electrode circles. There was also a trend toward a significant interaction among condition, electrode and hemisphere over the middle circle: $F(3, 57) = 2.89, p = .069$.

In the 600-900 ms (LPC) time window, there was a significant main effect of condition over the outer circle: $F(1, 19) = 4.99, p = .038$. The result indicates that consistent targets primed by inconsistent words (e.g., R+C–O– HEIGHT–FIGHT)
elicited less positive amplitudes relative to targets primed by consistent words (e.g., R+C+O– WHITE–FIGHT) at these sites.

From 600-900 ms there was also a significant interaction between condition and hemisphere over the inner circle: $F(1, 19) = 15.25, p = .001$; middle circle: $F(1, 19) = 12.1, p = .003$ and outer circle: $F(1, 19) = 9.13, p = .007$. The effect showed a trend toward a significant difference over the right hemisphere of the inner circle: $F(1, 19) = 3.0, p = .099$ and was significant over the right hemisphere of the middle circle: $F(1, 19) = 5.08, p = .036$ and outer circle: $F(1, 19) = 9.66, p = .006$, but was insignificant over the left hemisphere of the inner, middle and outer circles. This set of results reflects the fact that the consistency effect (i.e., the difference between targets primed by consistent vs. inconsistent words) was larger over the right relative to the left hemisphere.

**Orthography effect.** Figure 25 shows the waveforms elicited by rhyming consistent target words primed by orthographically dissimilar relative to orthographically similar consistent words (forming the orthography effect) at all 29 scalp electrode sites. This comparison is similar to those presented in other studies evaluating the effect of orthographic similarity on rhyme judgments (e.g., Rugg & Barrett, 1987; Weber-Fox et al., 2003). The orthography effect was notable as a mean amplitude difference between rhyming conditions such that the orthographically similar word pairs elicited more negative waveforms compared to the orthographically dissimilar word pairs in the 0-150 ms time window, producing a negative peak at about 100 ms post-target onset (N100). Furthermore, the orthographically similar word pairs elicited less positive waveforms in the 150-300 ms time window, producing a positive peak at about 200 ms post-target onset (P200). Additionally, the orthographically dissimilar word pairs elicited more
negative waveforms in the 300-500 ms time window, producing a negative peak at about 400 ms post-target onset (N400). Finally, the orthographically similar word pairs elicited less positive waveforms in the 500-700 ms time window, producing a positive peak at about 600 ms post-target onset (LPC).

In the 0-150 ms (N100) time window, there was a significant main effect of condition over the midline: $F(1, 19) = 11.06, p = .004$; inner circle: $F(1, 19) = 7.74, p = .012$; and middle circle: $F(1, 19) = 6.17, p = .022$ and a trend toward a significant main effect of condition over the outer circle: $F(1, 19) = 4.31, p = .052$. This set of results reflects the fact that the mean amplitude of the orthographically similar condition (e.g., R+C+O+ RIGHT–FIGHT) was more negative than the orthographically dissimilar condition (e.g., R+C+O– WHITE–FIGHT) in the 0-150 ms temporal window.

Furthermore, from 0-150 ms there was also a significant interaction between condition and electrode over the middle circle: $F(3, 57) = 3.67, p = .046$. Further post-hoc tests showed that there was a significant difference between the mean amplitudes elicited by the orthographically similar and dissimilar rhyming conditions over the middle circle at P3/4: $F(1, 19) = 13.99, p = .004$. This result reflects the fact that the orthography effect (the more negative amplitude elicited by the orthographically similar condition relative to the orthographically dissimilar condition on the N100 component) had a parietal distribution over the middle circle. There was also a trend toward a significant interaction between condition and hemisphere over the middle circle: $F(1, 19) = 3.99, p = .060$ and outer circle: $F(1, 19) = 3.76, p = .067$. The pattern of results suggests that the effect of orthography on the N100 had a right hemisphere distribution over the middle and outer circles.
In the 150-300 ms (P200) time window, there was a significant interaction between condition and electrode over the midline: $F(4, 76) = 3.90, p = .031$; inner circle: $F(2, 38) = 5.35, p = .021$; middle circle: $F(3, 57) = 10.53, p = .001$; and outer circle: $F(4, 76) = 3.95, p = .043$. Further post-hoc tests showed that there was a trend toward a significant difference between the mean amplitudes elicited by the orthographically similar and dissimilar rhyming conditions over the midline at Pz: $F(1, 19) = 7.39, p = .070$; and a significant difference over the middle circle at P3/4: $F(1, 19) = 7.62, p = .048$. This set of results reflects the fact that the orthography effect (the less positive amplitude elicited by the orthographically similar condition relative to the orthographically dissimilar condition on the P200 component) has a parietal distribution over the midline and middle circle.

In the 300-500 ms (N400) time window, there was a significant interaction between condition and electrode over the midline: $F(4, 76) = 5.15, p = .012$; middle circle: $F(3, 57) = 7.7, p = .006$ and outer circle: $F(4, 76) = 7.22, p = .002$. Further post-hoc tests showed that there was a significant or trending toward significant difference between the mean amplitudes elicited by the orthographically dissimilar and similar rhyming conditions over the midline at Fz: $F(1, 19) = 3.76, p = .067$; and Cz: $F(1, 19) = 3.39, p = .081$; middle circle at F3/4: $F(1, 19) = 4.57, p = .046$; FC5/6: $F(1, 19) = 4.81, p = .041$; and over the outer circle at F7/8: $F(1, 19) = 3.3, p = .085$; T3/4: $F(1, 19) = 5.16, p = .035$; and O1/2: $F(1, 19) = 3.55, p = .075$. These results reflect the fact that within the 300-500 ms time window, the orthography effect (the more negative amplitude elicited by the orthographically dissimilar condition relative to the orthographically similar condition on the N400 component) was larger over the frontal, central and temporal regions.
From 300-500 ms there was also a significant interaction between condition and hemisphere over the middle circle: $F(1, 19) = 5.77, p = .027$ and outer circle: $F(1, 19) = 5.85, p = .026$. The effect was significant over the left hemisphere of the middle circle: $F(1, 19) = 5.17, p = .035$, but did not reach significance over the right hemisphere of the middle circle, nor over either hemisphere of the outer circle. The orthography effect was larger over the left relative to the right hemisphere in the 300-500 ms time window over the middle circle.

In the 500-700 ms (LPC) time window, there was a main effect of condition over the midline: $F(1, 19) = 4.99, p = .038$. This result indicates that the mean amplitude of the orthographically similar condition (e.g., R+C+O+ RIGHT–FIGHT) was less positive than the orthographically dissimilar condition (e.g., R+C+O– WHITE–FIGHT) in the 500-700 ms window post-target onset.

From 500-700 ms there was also a significant interaction between condition and electrode over the middle circle: $F(3, 57) = 6.36, p = .008$ and outer circle: $F(4, 76) = 10.0, p = .000$. Further post-hoc tests showed that there was a significant or trending toward significant difference between the mean amplitudes elicited by the orthographically similar and dissimilar rhyming conditions over the middle circle at CP5/6: $F(1, 19) = 3.08, p = .095$; and P3/4: $F(1, 19) = 5.81, p = .026$ and over the outer circle at FP1/2: $F(1, 19) = 4.69, p = .043$; and O1/2: $F(1, 19) = 15.61, p = .001$. These results suggest that the orthography effect elicited in the 500-700 ms time window was largest over the occipital electrode sites.

Furthermore, from 500-700 ms, there was a significant interaction between condition and hemisphere over the middle circle: $F(1, 19) = 4.84, p = .040$ and a trend toward a
significant interaction between condition and hemisphere over the inner circle: $F(1, 19) = 3.05, p = .097$ and outer circle: $F(1, 19) = 3.87, p = .064$. Post-hocs conducted on the middle circle sites showed a trend toward significance over the right hemisphere of the middle circle: $F(1, 19) = 3.83, p = .065$ and was insignificant over the left hemisphere. In general the orthography effect in the 500-700 ms time window had a right hemisphere distribution.
Figure 23. Grand average event-related potentials elicited by rhyming conditions (solid lines) and non-rhyming conditions (dotted lines) from all 29 scalp electrodes. Data are plotted from 100 ms prior to the onset of the target word until 900 ms post-target onset, and negative is plotted up. The RE effect is observed within the 250-700 ms window post-target onset.
Figure 24. Grand average event-related potentials elicited by rhyming consistency incongruent (solid lines) and consistency congruent conditions (dotted lines) from all 29 scalp electrodes. Data are plotted from 100 ms prior to the onset of the target word until 900 ms post-target onset, and negative is plotted up. The consistency effect is observed within the 0-150 ms, 150-300 ms, 300-450 ms, 450-600 ms and 600-900 ms time windows post-target onset.
Figure 25. Grand average event-related potentials elicited by rhyming orthographically dissimilar (solid lines) and orthographically similar conditions (dotted lines) from all 29 scalp electrodes. Data are plotted from 100 ms prior to the onset of the target word until 900 ms post-target onset, and negative is plotted up. The orthography effect is observed within the 0-300 ms, 300-500 ms and 500-700 ms time windows post-target onset.
Non-rhyming conditions.

**Consistency effect.** Figure 26 shows the waveforms elicited by non-rhyming inconsistent target words primed by consistent versus inconsistent words (forming the consistency effect) at all 29 scalp electrode sites. The consistency effect was notable as a mean amplitude difference between the non-rhyming conditions such that the inconsistent target words elicited a less positive waveform when primed by consistent relative to inconsistent words in the 170-300 ms time window, producing a positive peak at around 200 ms post-target onset (P200). Furthermore, the inconsistent target words elicited a more negative waveform when primed by consistent relative to inconsistent words in the 300-450 ms time window, producing a negative peak at about 400 ms post-target onset (N400). Additionally, the inconsistent target words elicited a less positive waveform when primed by consistent relative to inconsistent words in the 450-700 ms time window, producing a positive peak at about 600 ms post-target onset (LPC).

In the 170-300 ms (P200) time window, there was a significant main effect of condition over the midline: $F(1, 19) = 4.80, p = .041$ and a trend toward a significant main effect of condition over the inner circle: $F(1, 19) = 3.87, p = .064$ and middle circle: $F(1, 19) = 3.25, p = .087$. This set of results confirms that the consistency congruent non-rhyming conditions (e.g., R–C+O–CHILD–COUGH) elicited a larger positive mean amplitude relative to the consistency incongruent non-rhyming conditions (e.g., R–C–O–CHURCH–COUGH) over the midline, inner and middle circle sites.

From 170-300 ms there was also a significant interaction between condition and electrode over the middle circle: $F(3, 57) = 5.40, p = .014$ and outer circle: $F(4, 76) = 5.00, p = .026$ and a trend toward a significant interaction between condition and
electrode over the midline: $F(4, 76) = 3.36, p = .052$. Further post-hoc tests showed that there was a significant or trend toward significant difference between the mean amplitudes elicited by the consistency congruent and incongruent non-rhyming pairs over the middle circle at F3/4: $F(1, 19) = 10.66, p = .016$; and FC5/6: $F(1, 19) = 6.90, p = .068$. This set of results reflects the fact that the consistency effect (the mean amplitude difference between the consistency congruent and incongruent non-rhyming conditions) in the 170-300 ms time window (P200 component) had a frontal and fronto-cental distribution over the middle circle. The same pattern was observed over the midline and outer circle even through the results did not reach significance.

In the 300-450 ms (N400) time window, there was a trend toward a significant main effect of condition over the inner circle: $F(1, 19) = 4.30, p = .052$ and middle circle: $F(1, 19) = 3.60, p = .073$. These results reflect the fact that the consistency incongruent non-rhyming conditions (e.g., R–C–O– CHURCH–COUGH) elicited a more negative mean amplitude relative to the consistency congruent non-rhyming conditions (e.g., R–C+O– CHILD–COUGH) over the inner and middle electrode sites.

In the 300-450 ms time window, there was also a significant interaction between condition and electrode over the midline: $F(4, 76) = 3.66, p = .032$; middle circle: $F(3, 57) = 4.55, p = .024$ and outer circle: $F(4, 76) = 6.57, p = .007$. Further post-hoc tests showed that there was a significant or trend toward significant difference between the mean amplitudes elicited by the consistency congruent and incongruent non-rhyming pairs over the midline at Fz: $F(1, 19) = 6.78, p = .085$; middle circle at F3/4: $F(1, 19) = 6.43, p = .080$; FC5/6: $F(1, 19) = 7.88, p = .044$; and outer circle at F7/8: $F(1, 19) = 9.53, p = .030$. This set of results reflects the fact that the consistency effect (the mean
amplitude difference between the consistency congruent and incongruent non-rhyming conditions) in the 300-450 ms time window (N400) had frontal and fronto-central distribution over the midline, middle and outer circle electrode sites.

In the 450-700 ms (LPC) time window, there was a significant interaction between condition and electrode over the midline: $F(4, 76) = 3.16, p = .044$; middle circle: $F(3, 57) = 4.17, p = .036$; and outer circle: $F(4, 76) = 6.22, p = .007$. Further post-hoc tests showed that the mean amplitudes elicited by the consistency congruent and consistency incongruent non-rhyming conditions did not reach significance over any of the midline, middle or outer circle electrode sites. However, the patterns of results revealed that the consistency incongruent non-rhyming conditions (e.g., R–C–O– CHURCH–COUGH) elicited a less positive mean amplitude relative to the consistency congruent non-rhyming conditions (e.g., R–C+O– CHILD–COUGH) over the pre-frontal, frontal and fronto-central electrode sites. There was also a trend toward a significant interaction among condition, electrode and hemisphere over the inner circle: $F(2, 38) = 2.56, p = .091$.

**Orthography effect.** Figure 27 shows the waveforms elicited by non-rhyming inconsistent target words primed by orthographically dissimilar versus orthographically similar inconsistent words (forming the orthography effect) at all 29 scalp electrode sites. A subset of 10 Chinese-English bilingual participants who performed this condition with most accuracy was included in this analysis. That is because performance on this condition appeared to be modulated by English (L2) proficiency. This comparison is similar to those presented in other studies evaluating the effect of orthographic similarity on non-rhyme judgments (e.g., Rugg & Barrett, 1987; Weber-Fox et al., 2003). The orthography effect was notable as a mean amplitude difference between non-rhyming
conditions such that the orthographically dissimilar word pairs elicited more negative waveforms compared to the orthographically similar word pairs on the negative-going component (N400) in the 250-450 ms epoch, but more positive waveforms on the positive-going component (LPC) in the 600-750 ms epoch post-target onset.

In the 250-450 ms (N400) time window, there was a significant main effect of condition over the midline: $F(1, 9) = 8.81, p = .016$ and outer circle: $F(1, 9) = 5.53, p = .043$. This result reflects the fact that the mean amplitude of the orthographically dissimilar condition (e.g., R–C+O– CHILD–COUGH) was more negative than the mean amplitude of the orthographically similar condition (e.g., R–C+O+ DOUGH–COUGH) in the 250-450 ms post-target onset. There was also a trend toward a significant interaction among condition, electrode and hemisphere over the outer circle: $F(4, 36) = 3.27, p = .057$.

In the 600-750 ms (LPC) time window, there was a significant interaction between condition and electrode over the inner circle: $F(2, 18) = 9.41, p = .008$ and a trend toward a significant interaction between condition and electrode over the midline: $F(4, 36) = 3.56, p = .064$. Further post-hoc tests at the inner circle sites showed that there was a trend toward a significant difference between the mean amplitudes elicited by the orthographically similar and dissimilar non-rhyming conditions at C3/4: $F(1, 9) = 3.91; p = .079$. This result suggests that the orthographically dissimilar condition elicited more positive mean amplitudes relative to the orthographically similar condition in the 600-750 ms time window, the effect being largest over the frontal and central electrode sites.
Figure 26. Grand average event-related potentials elicited by non-rhyming consistency incongruent (solid lines) and consistency congruent conditions (dotted lines) from all 29 scalp electrodes. Data are plotted from 100 ms prior to the onset of the target word until 900 ms post-target onset, and negative is plotted up. The consistency effect is observed within the 200-450 ms and 500-700 ms time windows post-target onset.
Figure 27. Grand average event-related potentials elicited by non-rhyming orthographically dissimilar (solid lines) and orthographically similar conditions (dotted lines) from all 29 scalp electrodes. Data are plotted from 100 ms prior to the onset of the target word until 900 ms post-target onset, and negative is plotted up. The orthography effect is observed within the 250-450 ms and 600-750 ms time windows post-target onset.
Discussion

Experiment 2 of Study 2 sought evidence that bilinguals with a logographic first language (L1 – Chinese) transferred reading strategies to their orthographically deep second language (L2 – English). Chinese-English bilinguals who were immersed in an English-speaking environment (the US) made rhyme judgments of semantically unrelated English word pairs presented sequentially in the visual modality, while behavioral responses and event-related potentials (ERPs) were recorded. The spelling-sound consistency and orthographic similarity of rhyming and non-rhyming prime-target pairs were varied systematically.

Rhyming Effect

Behavioral measures indicated that rhyming targets elicited more accurate responses than non-rhyming targets. These results are consistent with the performance of Spanish-English bilinguals in Experiment 1 and with the performance of English monolinguals in Study 1, as well as with the findings of previous studies using the visual rhyme-priming paradigm with word stimuli (e.g., McPherson et al., 1998; Rugg, 1984a). However, unlike the pattern of results observed in the Spanish-English bilingual and English monolingual groups and previous reports with monolingual English speakers, the Chinese-English bilingual group did not show response latency facilitation for the rhyming relative to the non-rhyming conditions. Electrophysiological measures revealed that non-rhyming targets elicited more negative N400 and less positive LPC waveforms than rhyming targets in the 250-700 ms time window. The pattern of results observed over the N400 is consistent with those elicited by the Spanish-English bilingual and English monolingual groups. Furthermore, this pattern of results replicates the rhyming
effect found by Chen and colleagues (2010) in Chinese-English bilinguals making rhyme judgment decisions about English (L2) word pairs. The effect is also consistent with findings reported in most previous ERP studies using the visual rhyme-priming paradigm with letter, word and nonword stimuli in English (L1; e.g., Coch, et al., 2011; Coch et al., 2008a, b; Grossi et al., 2001; Khateb et al., 2007; Rugg, 1984a, b; Weber-Fox et al., 2003) and Spanish (L1) word pairs (Perez-Abalo et al., 1994) and Chinese (L1) word pairs (Chen et al., 2010).

The N400 effect in the rhyme-priming paradigm has been hypothesized to be a mismatch-related response that occurs when the phonological representation activated by the target word differs from that of the prime word (Khateb et al., 2007; Kramer & Donchin, 1987; Rugg, 1984a). According to the spreading activation account, a reduction of the N400 is noted in response to rhyming relative to non-rhyming conditions because when participants access the phonological representation of the prime, the activation spreads automatically to phonologically related nodes, facilitating the processing of phonologically similar relative to phonologically dissimilar targets.

The more positive LPC elicited in response to rhyming relative to non-rhyming conditions may reflect increased response monitoring for the rhyming relative to the non-rhyming conditions. The same pattern of results was noted in English monolinguals and Spanish-English bilinguals. As in the case of Spanish-English bilinguals, the LPC elicited by Chinese-English bilinguals may be related to the attention and monitoring processes involved in making rhyme judgments in the second language.

It should be noted that the design of the study was not optimal for investigating the RE given that a different set of targets was used in the rhyming conditions (i.e., consistent
target words) than in the non-rhyming conditions (i.e., inconsistent target words). That is because the study was designed specifically to evaluate the effects of spelling-sound consistency and orthographic similarity on activating phonology from print.

**Consistency Effect**

Behavioral measures of response time and accuracy showed no difference between rhyming consistent target words primed by consistent (i.e., congruent in consistency to the target: R+C+O– WHITE–FIGHT) relative to inconsistent (i.e., incongruent in consistency to the target: R+C–O– HEIGHT–FIGHT) words. The lack of a consistency effect in the behavioral results may be related to a number of factors. While it may suggest that Chinese-English bilinguals are employing a large grain size in reading English words, lexical access being relatively slow when done in bilinguals’ weaker L2 (Ivanova & Costa, 2008), it may also indicate that Chinese-English bilinguals are careful with their rhyme decisions, taking their time in responding to each condition. However, electrophysiological measures revealed that rhyming consistent targets primed by consistent words (e.g., R+C+O– WHITE–FIGHT) elicited more negative N100 (0-150 ms), P200 (150-300 ms), early N400 (300-450 ms) and late N400 (450-600 ms) waveforms than when primed by inconsistent words (e.g., R+C–O– HEIGHT–FIGHT). Furthermore, consistency congruent rhyming conditions elicited more positive LPC (600-900 ms) waveforms relative to consistency incongruent rhyming conditions. These mean amplitude differences evidenced throughout the ERP epoch may suggest a spillover effect from the processing of the prime. Since Chinese-English bilinguals are making rhyme judgments in their second language, they are slower than English monolinguals and even than Spanish-English bilinguals in processing the phonological representation
of the prime and of the subsequent target, so their processing of consistency gets dragged throughout the epoch. This slowed down processing may not only reflect the fact that Chinese-English bilinguals are processing in their weaker L2 (i.e., English), but may also reflect the phonological and orthographic distance between their L1 (i.e., Chinese) and L2.

As noted earlier in this chapter, the N100-P200 component complex has been linked to individual letter identification (Rey et al., 2009). The fact that Chinese-English bilinguals clearly elicit both components in the processing of consistency congruent relative to incongruent rhyming conditions may suggest that they are paying close attention to the visual features of the stimuli, such as letter font and size (Chauncey et al., 2008; Rey et al., 2009).

The P200 has been linked to print-to-sound consistency, such that a more positive P200 has been associated with native Chinese speakers’ reading of low consistency relative to high consistency Chinese characters matched in phonetic combinability (i.e., the number of phonograms that share a phonetic radical, also known as “friends”; Lee et al., 2007) or confounded with phonetic combinability (e.g., Hsu et al., 2009). This effect has been interpreted as an early orthographic or phonological activation associated with the early stages of visual word cognition (Hsu et al., 2009; Lee et al., 2007). The fact that the Chinese-English bilinguals in this experiment elicited more positive P200 amplitudes in response to consistent targets primed by consistent (e.g., R+C+O– WHITE–FIGHT) relative to inconsistent (e.g., R+C–O– HEIGHT–FIGHT) words, which is the reversed effect than that they are reported to produce in their L1 (e.g., Hsu et al., 2009; Lee et al., 2007), may suggest that they are activating a small grain size in response to consistency
congruent prime-target word pairs, but a larger grain size in response to consistency incongruent prime-target word pairs. Since they use a large grain size in reading Chinese words, Chinese-English bilinguals may be facilitated by inconsistent primes in the early stages of word recognition. Alternatively, Chinese-English bilinguals’ enhanced visual analysis skills transferred from their L1 (e.g., Wang et al., 2003) may have caused them to identify more graphemic dissimilarity within the consistency congruent relative to the consistency incongruent prime-target word pairs. Moreover, word with inconsistent rimes may be more frequent in their L2 lexicon, therefore eliciting a reduced P200 relative to words with consistent mappings (e.g., Rugg & Doyle, 1992).

The N400, which has been reported as a mismatch-related negativity that occurs in response to phonological (Khateb et al., 2007; Rugg, 1984a) and orthographic (Kramer & Donchin, 1987; Rugg & Barrett, 1987; Weber-Fox et al., 2003) dissimilarity, may also be sensitive to a mismatch in spelling-sound consistency between prime-target word pairs. The fact that Chinese-English bilinguals elicited more negative N400 mean amplitudes in response to consistent targets paired with inconsistent (e.g., R+C–O– HEIGHT–FIGHT) relative to consistent (e.g., R+C+O– WHITE–FIGHT) primes may suggest that they employ more cognitive resources in processing English words with inconsistent relative to consistent spelling-sound mappings. Alternatively, this may suggest that Chinese-English bilinguals are sensitive to the mismatch in consistency between prime-target word pairs. Nonetheless, the mean amplitude difference observed in response to Chinese speakers’ processing of L2 spelling-sound consistency goes into the opposite direction when Chinese speakers process consistency in their L1. More precisely, Chinese-English bilinguals have been reported to elicit more negative N400 amplitudes in response to high
relative to low consistency Chinese characters (e.g., Hsu et al., 2009; Lee et al., 2007). The authors of the studies reporting this effect in native Chinese speakers argue that the increased N400 amplitude in response to high consistency Chinese characters is caused by competition among lexical candidates that share a phonetic radical. This interpretation is consistent with the effect of orthographic neighborhood size over the N400 reported in previous studies with native speakers of English (Holcomb et al., 2002) and Spanish (Müller, Duñabeitia, & Carreiras, 2010). The difference pattern in the modulation of the N400 noted in the current study suggests that the processing of consistency differs across monolinguals and bilinguals. That is because a bilingual’s neighborhood of friend and rival pronunciations in the L2 is not comparable to that of a monolingual’s, as it may differ as a function of the bilingual’s L2 proficiency, orthographic and phonological distance from the L1 and language dominance. These differences may cause bilinguals to set an expectation of consistency for the L2 that is modulated by the consistency of their L1.

The effect of consistency over the LPC, a component that has been related to conscious reprocessing in the attempt to resolve response uncertainty (e.g., Kolk & Chwilla, 2007), suggest that Chinese-English bilinguals are employing more cognitive resources in responding to consistency congruent relative to consistency incongruent rhyming conditions. Given that Chinese-English bilinguals are performing the task in an L2 with a distinct script than their L1, their processing of L2 spelling-sound mappings may be a slower process than in bilinguals reading two alphabetic orthographies, requiring more conscious attention.
Alternatively, the pattern of the consistency effect throughout the ERP epoch, characterized by a generalized negative shift for the consistency incongruent relative to the consistency congruent rhyming conditions, suggests that the effects seen here are carried over from the processing of the primes. In order to test this hypothesis, the analysis needs to be re-done after time-locking the ERP to the presentation of the prime instead of the target to see participants’ electrophysiological response to the prime.

Behavioral measures of response time showed facilitation for non-rhyming inconsistent target words primed by consistent (consistency incongruent: R–C–O–CHURCH–COUGH) relative to inconsistent (consistency congruent: R–C+O–CHILD–COUGH) words. Electrophysiological measures revealed that consistent primes paired with inconsistent targets (e.g., R–C–O–CHURCH–COUGH) elicited a larger P200 (170-300 ms) mean amplitude relative to inconsistent primes paired with inconsistent targets (e.g., R–C+O–CHILD–COUGH). Furthermore, consistency incongruent conditions elicited more negative N400s (300-450 ms), but more positive LPCs (450-700 ms) relative to the consistency congruent conditions.

The fact that a larger P200 amplitude was elicited by consistency congruent (e.g., R–C+O–CHILD–COUGH) relative to the consistency incongruent (e.g., R–C–O–CHURCH–COUGH) non-rhyming conditions suggest that the P200 modulation observed here may be in response to the degree of inconsistency associated with the word pair, or with the inconsistency of the prime, with a larger positivity elicited in response to conditions in which both primes and targets were inconsistent (e.g., R–C+O–CHILD–COUGH) relative to conditions in which only the target was inconsistent (e.g., R–C–O–CHURCH–COUGH). The modulation of the P200 in response to consistency observed
here replicates the results of previous studies (Hsu et al., 2009; Lee et al., 2007) that investigated Chinese speakers’ sensitivity to print-to-sound consistency in their native language.

Furthermore, the fact that a more negative N400 amplitude was elicited by the consistency incongruent relative to the congruent non-rhyming conditions suggests once again that the N400 may be sensitive to the prime-target mismatch in spelling-sound consistency. Alternatively, the processing of the consistent prime word (e.g., CHURCH) found in the consistency incongruent non-rhyming conditions may involve competition among friend pronunciations of the rime, which would cause an increase in the N400 amplitude (see Holcomb et al., 2002; Hsu et al., 2009; Lee et al., 2007; and Müller et al., 2010 for a review of this interpretation).

Lastly, the more positive LPC waveform elicited by the consistency congruent (e.g., R–C+O– CHILD–COUGH) relative to the consistency incongruent (e.g., R–C–O– CHURCH–COUGH) non-rhyming conditions suggest that Chinese-English bilinguals employ more conscious resource in making non-rhyming decisions when both prime-target word pairs are inconsistent than when a consistent prime is paired with a consistent target.

Chinese-English bilinguals’ performance across the rhyming and non-rhyming conditions suggests that they show sensitivity to the consistency incongruence in prime-target word pairs. This sensitivity to English (L2) spelling-sound consistency found in Chinese-English bilinguals is surprising, considering that native speakers of Chinese were expected to transfer a large grain size from the L1 to the L2 and consequently be unaffected by L2 spelling-sound consistency. Their sensitivity to English consistency
seems to suggest that Chinese-English bilinguals acknowledged English as having a more transparent writing system than Chinese, and as a result they associated more consistency with English spelling-sound mappings than there actually is. Consequently, they adopted a smaller grain size than necessary, so they encountered more difficulty than expected in activating the correct phonological representations of inconsistent English words.

**Orthography Effect**

Behavioral measures of response time and accuracy showed facilitation for rhyming consistent target words primed by (consistency congruent) orthographically similar (e.g., R+C+O+ RIGHT–FIGHT) relative to orthographically dissimilar (e.g., R+C+O– WHITE–FIGHT) words. This result is consistent with the findings of Study 1 and Experiment 1 of Study 2 and also replicates the findings of previous studies investigating the role of orthographic similarity in visual rhyme judgments (e.g., Kramer & Donchin, 1987; Polich et al., 1983; Rugg & Barrett, 1987; Weber-Fox et al., 2003).

Electrophysiological measures revealed that rhyming targets primed by orthographically similar words (e.g., R+C+O+ RIGHT–FIGHT) elicited more negative N100 (0-150 ms) waveforms, but less positive P200 (150-300 ms) waveforms relative to rhyming targets primed by orthographically dissimilar words (e.g., R+C+O– WHITE–FIGHT).

Furthermore, rhyming targets primed by orthographically dissimilar words (e.g., R+C+O– WHITE–FIGHT) elicited more negative N400 (300-500 ms) waveforms and more positive LPC (500-700 ms) waveforms relative to rhyming targets primed by orthographically similar words (e.g., R+C+O+ RIGHT–FIGHT). The modulation of the N400 component is consistent with the findings of previous studies that manipulated the
degree of orthographic overlap between primes and targets within rhyming conditions (e.g., Rugg & Barrett, 1987; Weber-Fox et al., 2003).

As noted earlier, the N100-P200 component complex may be involved in the early stages of visual analysis and letter identification (Rey et al., 2009). The fact that both components are modulated by the orthography manipulation may suggest that Chinese-English bilinguals show sensitivity to orthographic similarity from the early stages of processing. The fact that Chinese-English bilinguals elicited a less positive P200 in response to the orthographically similar relative to the orthographically dissimilar conditions replicates the effect reported by Liu and colleagues (2003) and suggests that participants are facilitated by the orthographic similar conditions in the process of mapping orthography to sound. The modulation of the P200 in response to the degree of orthographic similarity between prime-target word pairs suggests that the demands on visual-orthographic processes imposed by reading a logographic system cause native speakers of Chinese to be attentive to orthographic information in their L2 (Wang et al., 2003).

The fact that the orthographically similar rhyming word pairs elicited less negative N400 amplitudes relative to orthographically dissimilar rhyming word pairs brings further evidence that the phonological and orthographic similarity between prime-target word pairs forms an additive effect that modulates the N400, causing facilitation for the orthographically similar relative to the orthographically dissimilar rhyming conditions. This orthography effect noted over the N400 component is consistent with the effect reported in English monolinguals (Study 1) and in Spanish-English bilinguals.
(Experiment 1 of Study 2) and with the N450 component described by Rugg and Barrett (1987).

The more positive LPC elicited in the processing of the orthographically dissimilar relative to the orthographically similar conditions reflects the fact that more cognitive resources are needed to produce a rhyme decision in response to the orthographically dissimilar relative to the orthographically similar conditions. This pattern is most likely due to the convergence of orthographic and phonological cues activated by the orthographically similar rhyming word pairs (e.g., R+C+O+ RIGHT–FIGHT) and reflects facilitation in processing the orthographically similar relative to the orthographically dissimilar (e.g., R+C+O– WHITE–FIGHT) rhyming conditions.

Behavioral measures of response time and accuracy showed inhibition for non-rhyming inconsistent target words primed by (consistency congruent) orthographically similar (R–C+O+ DOUGH–COUGH) relative to orthographically dissimilar (e.g., R–C+O– CHILD–COUGH) words. This result is consistent with the findings of Study 1 and Experiment 1 of Study 2 and also replicates the findings of previous studies investigating the role of orthographic similarity in visual rhyme judgments (e.g., Kramer & Donchin, 1987; Polich et al., 1983; Rugg & Barrett, 1987; Weber-Fox et al., 2003).

Electrophysiological measures revealed that orthographically similar non-rhyming conditions (e.g., R–C+O+ DOUGH–COUGH) elicited less negative N400 (250-450 ms) waveforms relative to orthographically dissimilar non-rhyming conditions (e.g., R–C+O– CHILD–COUGH). Furthermore, the orthographically similar non-rhyming conditions elicited less positive LPC waveforms relative to the orthographically dissimilar non-rhyming conditions.
The more negative N400 waveform elicited by the orthographically dissimilar relative to the orthographically similar conditions may suggest that the N400 is modulated by the mismatch in phonological and orthographic cues. Alternatively, the difference noted on the N400 may be related differential lexical access between the inconsistent item pairs as a function of their degree of orthographic similarity. It may be that the orthographically similar word pairs have a smaller lexical neighborhood relative to the orthographically dissimilar word pairs.

The more positive LPC waveforms elicited in response to the orthographically dissimilar relative to the orthographically similar non-rhyming conditions suggest that Chinese-English bilinguals allocate less cognitive resources to resolving the conflicting orthographic and phonological cues activated by the orthographically similar non-rhyming conditions than to the orthographically dissimilar non-rhyming conditions. This pattern suggests that Chinese-English bilinguals’ visual analysis skills may work against them in an inconsistent L2, as they may be incorrectly facilitated by orthographic similarity. The pattern of the LPC may suggest that Chinese-English bilinguals may have a hard time tuning into the conflicting cues activated by the orthographically similar non-rhyming conditions, so they may employ more conscious attention to the accuracy of their non-rhyming responses to the orthographically dissimilar conditions.

Chinese-English bilinguals’ processing of orthographic similarity across rhyming and non-rhyming conditions suggests that they are facilitated by orthographic similarity in making rhyming decisions and inhibited in making non-rhyme decisions. The same overall pattern of results was found in English monolinguals and Spanish-English bilinguals. The results show that Chinese-English bilinguals are sensitive to the
orthographic similarity across word pairs in an L2 that uses a different script from their L1. This may suggest that Chinese-English bilinguals transfer the visual-orthographic processing skills developed in the reading of a logographic system (Wang et al., 2003) to the processing of an L2 alphabetic script. However, even though native Chinese speakers experience dissociation between orthographic and phonological cues in their L1 (Chen et al., 2010), the fact that they show a similar pattern of behavioral facilitation and inhibition in response to L2 orthographic similarity as Spanish-English bilinguals suggests that Chinese-English bilinguals expect English spelling-sound mappings to be more consistent than they are in reality.

Nonetheless, Spanish-English bilinguals’ allocation of greater cognitive resources to the processing of diverging cues from orthography and phonology relative to Chinese-English bilinguals may suggest that Spanish-English bilinguals find it more difficult than Chinese-English bilinguals to dissociate orthography from phonology (i.e., the expectation that similar orthography leads to similar phonological representations) when processing a deep L2 orthography, such as that of English. This may be a reflection of bilinguals’ L1 script and orthographic depth. Cross-linguistic transfer should be easier across two alphabetic orthographies (i.e., Spanish and English) than across orthographies with different scripts (i.e., Chinese and English; Melby-Lervag & Lervag, 2011). More specifically, orthographic similarity across word pairs in the L2 may prime an expectation of phonological similarity more strongly in bilinguals whose L1 and L2 share the same script than in bilinguals whose two language differ in script. Furthermore, in shallow orthography such as that of Spanish, two words do not rhyme with each other without sharing, at least in part, the spelling of the rime. In contrast, in a deep
orthography, such as that of Chinese, two characters can rhyme with each other and have different orthographic structures (Chen et al., 2010).

**General Discussion**

The findings reported in Experiments 1 and 2 of the current study suggest that the word reading strategies bilinguals adopt in an orthographically deep L2 may vary as a function of the difference in orthographic depth and script between their L1 and L2. The Spanish-English bilinguals tested in this study transfer expectations of spelling-sound consistency from their shallow L1 orthography to their deep L2 orthography, adopting a small grain size in reading English. This interpretation is supported by previous studies reported in the literature (e.g., Dressler & Kamil, 2006; Mumtaz & Humphreys, 2001; Sasaki, 2005; Spencer & Hanley, 2003). Spanish-English bilinguals’ cross-linguistic transfer of reading strategy from the L1 to the L2 may be facilitated by the fact that both orthographies share the same Latin alphabetic script (e.g., Melby-Lervag & Lervag, 2011). This common ground between the bilinguals’ two orthographies facilitates the transfer of L1 orthographic processing skills to the L2 (e.g., Bialystok et al., 2005; Cárdenas-Hagan et al., 2007; Sun-Alperin, & Wang, 2011). This is not surprising, given that a small orthographic distance between bilinguals’ two languages has been reported to contribute positively to L2 reading (e.g., Akamatsu, 1999; Bialystok et al., 2005; Koda, 1989, 1999, 2005b; Muljani et al., 1998). Nonetheless, the orthography-to-phonology activation across the bilinguals’ two languages may also produce interference effects when orthographic representations map to distinct phonological codes across languages (Schwartz et al., 2007).
In contrast, the Chinese-English bilinguals tested in this study do not transfer a reading unit preference from the L1 to the L2. Given that in the case of Chinese-English bilinguals the factors of orthographic depth and script are confounded, it is difficult to say with certainty whether the effect is caused by their non-transparent orthography-to-phonology mappings, or by their logographic script. However, one possible explanation might be that the difference in scripts between their L1 (logographic) and L2 (alphabetic) may inhibit the cross-linguistic transfer of reading strategies. The difference in script between their L1 and L2 may act like a language (mode) cue. Consequently, Chinese-English bilinguals may become more aware of the differences between their L1 and L2 writing systems and form an expectation about the degree of spelling-sound consistency associated with their L2 that accounts for these differences. More specifically, the fact that Chinese-English bilinguals are facilitated by English spelling-sound consistency may suggest that they expect English spelling-sound mappings to be more consistent than they are. This suggests that they may judge the spelling-sound consistency of English in comparison with the degree of consistency encountered in Chinese. This finding is inconsistent with the results reported by Tan and colleagues (2003), who have found that native speakers of Chinese showed a preference for using a large grain size, associated with reading Chinese characters, when reading English (L2), rather than relying on English spelling-sound conversion rules to activate phonology. However, the authors of this study did not manipulate the consistency or regularity of the spelling-sound mappings of the English stimuli. Therefore, it is not clear what the ratio of consistent to inconsistent English words might have been. Furthermore, the Chinese and English word pairs were presented within the same experiment, blocked by language. It may be that the
presentation of Chinese (L1) and English (L2) words in the same experiment boosted the co-activation of L1 reading strategy (e.g., Jared & Kroll, 2001), causing the sequential Chinese-English bilinguals to use a large grain size in the processing of both English and Chinese words.

Alternatively, the preference for consistency shown by the Spanish-English and Chinese-English bilinguals tested in this study may reflect a default strategy that bilinguals adopt in their weaker L2. If this is the case, it may suggest that the search for consistency and regularity in the input is modulated by language proficiency, such that less proficient readers start out with an expectation of spelling-sound consistency and regularity and gradually calibrate the use of small and large reading units as their experience increases.
Chapter 6

STUDY 3

Bilinguals’ Spelling-Sound Consistency Preference in a Deep L2 when their Shallow L1 is Covertly versus Overtly Co-activated

Study 3 evaluated whether the presence of both L1 and L2 words in the same task facilitates the transfer of consistency expectations from a relatively shallow L1 (i.e., Dutch: Seymour et al., 2003) to a deep L2 (i.e., English) orthography relative to L2-only reading contexts. For this purpose, Dutch-English bilinguals living in the Netherlands were tested either on an English (Experiment 1) or Dutch-English (Experiment 2) rhyme judgment task. The data collected from the participant group assigned to the English rhyme judgment task served as baseline comparison for the data collected from the group assigned to the Dutch-English rhyme judgment task.

When tested in the L2 (i.e., English), Dutch-English bilinguals were expected to approach English reading with a small grain size, showing facilitation for consistent spelling-sound mappings and orthographic similarity in the presence of converging phonological cues. The preference for consistency was expected to be enhanced when bilinguals completed the cross-linguistic Dutch-English rhyme judgment task than the English rhyme judgment task because it should be more difficult to inhibit L1 reading strategies when both the L1 and the L2 are overtly co-activated within the same task than when the task is performed solely in the L2. If consistency mediates competition between Dutch and English phonological activations, then Dutch-English bilinguals were expected to show slower response times, lower accuracy levels and a larger N400 amplitude to English inconsistent versus consistent targets primed by rhyming and non-rhyming Dutch
The N400 has been described as a mismatch-related index of phonological processing (Grossi et al., 2001; Khateb et al., 2007; Rugg, 1984a) and it has been reported to be sensitive to the degree of print-to-sound consistency (Hsu et al., 2009; Lee et al., 2007). In contrast, if Dutch-English bilinguals show facilitation for consistent spelling-sound mappings in both L2-only and cross-linguistic contexts, then the transfer of consistency expectations from a shallow L1 to a deep L2 orthography is not modulated by the degree of co-activation of consistency expectations associated with the L1. Furthermore, the rhyming effect typically found in the ERP literature (e.g., Chen et al., 2010; Grossi et al., 2001; Weber-Fox et al., 2003) is expected to be replicated in this study, with Dutch-English bilinguals demonstrating increased negative amplitudes peaking at around 350-450 ms post-stimulus in response to non-rhyming versus rhyming targets in both the English and Dutch-English rhyme judgment tasks.

**Experiment 1: Bilinguals’ Processing of Consistency in an L2-Only Context**

**Method**

**Participants**

Results are presented for 16 native speakers of Dutch (4 male; mean age = 23.5 years; age range = 18 to 30 years) from Radboud University, Nijmegen. All participants were right-handed, had normal or corrected-to-normal vision, and no history of neurological dysfunction, language or reading disorders. All were volunteers paid €30 for participating in two experimental sessions, one in which EEG was collected during performance of the primary rhyme judgment task and one in which participants completed a battery of behavioral measures to assess their phonological working
memory, reading skills, language proficiency and individual differences in cognitive resources.

A total of 19 participants had initially completed the study. Data from 2 participants were excluded from the final analysis due to an insufficient number of artifact-free trials. One other participant was excluded from the study for being left-handed.

Participants had achieved high levels of English proficiency but had maintained dominance in the native language, which was their primary language of instruction in school through eighth grade. Participants had no consistent exposure to English before age of 6. Using a 7-point rating system, native Dutch speakers rated their English proficiency as averaging 6.03 (SD 0.42).

**Stimuli and Procedure**

Experiment 1 of Study 3 used the same stimuli and procedure as Study 2 (see page 71 for a review of the English rhyme judgment and word identification tasks).

The behavioral testing session followed the same structure as the one described in Study 2, with the difference that the Memory for Digits, L1 reading, L1 picture naming and operation span tasks were administered in Dutch. Dutch reading ability was assessed with the one-minute word reading test (Brus & Voeten, 1973) and the Klepel nonword reading test (Van den Bos, Spelberg, Scheepstra, & De Vries, 1994). These tests measure the number of words and nonwords read correctly in 1 minute and 2 minutes, respectively.

**EEG Recording Procedure**

Experiment 1 of Study 3 used the electrode setup and recoding procedure described on page 63.
Data Analysis

Experiment 1 of Study 3 used the same data analysis strategy as Study 1 (see page 75 for a review), with the exception of the electrode sites analyzed. For Study 3 sites were divided into: midline (FzA, Fz, Cz, Pz, Oz) and two concentric rings of lateral electrode sites (middle circle: F3A/F4A, F3/F4, LT/RT, LTP/RTP, P3/P4, P3P/P4P; outer circle: F7A/F8A, F7/F8, LAT/RAT, T5/T6, OL/OR). Furthermore, in order to be included in the analyses, participants had to have produced at least 20 correct, artifact-free responses per condition and to have at least 60 percent overall accuracy in the rhyming and non-rhyming conditions. These inclusion criteria are similar to the ones used in Study 2 since in both studies participants performed the task in their second language, which involved a greater degree of difficulty relative to performing the task in one’s native language, as was the case for the participants tested in Study 1 (i.e., English monolinguals).

The mean amplitude of the rhyming effect was calculated in the 300-900 ms time window post-target onset. In addition, smaller temporal windows were chosen based on visual observation of the grand averages to evaluate the effects of the consistency and orthographic similarity manipulations that were unique to the current sets of studies. Specifically, the mean amplitude of spelling-sound consistency effect was evaluated for two windows in the rhyming conditions (300-450 ms and 450-600 ms) and two windows in the non-rhyming conditions (400-500 ms and 550-650 ms). Furthermore, the mean amplitude of orthographic similarity effect was evaluated for two windows within the rhyming conditions (250-400 ms and 400-600 ms) and three windows within the non-rhyming conditions (250-400 ms, 450-600 ms and 600-900 ms). Additionally, the peak latency difference between the orthographically similar and dissimilar word pairs was
evaluated within the non-rhyming conditions.
Results

Behavioral Results

The behavioral results are shown in Figures 28 and 29. In a comparison of responses to all rhyming and all non-rhyming conditions, there was a main effect of condition on response times that showed a trend toward significance: $F(1, 15) = 3.19, p = .095$, but there was no effect of condition on response accuracy. The results reflect the fact that Dutch-English bilinguals were marginally faster in responding to rhyming relative to non-rhyming conditions, but equally accurate.

Rhymin conditions. There was a significant effect of prime consistency on rhyming response times: $F(1, 15) = 6.11, p = .026$ and accuracy: $F(1, 15) = 42.31, p = .000$, indicating that Dutch-English bilingual participants were slower and less accurate in responding to rhyming consistent target words when primed by inconsistent (e.g., R+C–O–HEIGHT–FIGHT) relative to consistent words (e.g., R+C+O–WHITE–FIGHT) with limited orthographic similarity to the target.

There was also a significant effect of orthographic similarity on rhyming response times: $F(1, 15) = 228.42, p = .000$ and accuracy: $F(1, 15) = 31.89, p = .000$, indicating that Dutch-English bilinguals were faster and more accurate in responding to rhyming targets primed by words with high (e.g., R+C+O+RIGHT–FIGHT) rather than low (e.g., R+C+O–WHITE–FIGHT) degrees of orthographic similarity to the target. Recall that when prime-target orthographic similarity was varied, spelling-sound consistency was held constant.

Non-rhyming conditions. There was no effect of prime consistency on non-rhyming response times or accuracy, indicating that participants were equally fast and accurate in
responding to non-rhyming inconsistent target words when primed by inconsistent (e.g., R–C+O– CHILD–COUGH) or consistent words (e.g., R–C–O– CHURCH–COUGH) with limited orthographic similarity to the target.

However, there was a significant effect of prime-target orthographic similarity on non-rhyming response times: $F(1, 15) = 80.78, p = .000$ and accuracy: $F(1, 15) = 119.21, p = .000$, indicating that Dutch-English bilinguals were slower and less accurate in responding to non-rhyming targets primed by orthographically similar (R–C+O+ DOUGH–COUGH) than dissimilar words (e.g., R–C+O– CHILD–COUGH). Recall that when prime-target orthographic similarity was varied, spelling-sound consistency was held constant.

*Figure 28.* Mean reaction times (in ms) for rhyming and non-rhyming conditions. Error bars show 95% confidence intervals.
**Figure 29.** Mean accuracy rates (in percentages) for rhyming and non-rhyming conditions. Error bars show 95% confidence intervals.

### Electrophysiological Results

The waveforms elicited during the task showed a series of peaks consistent with previous visual word recognition studies. Specifically, there was a clear negative peak around 100 ms (N100), followed by a positive peak around 200 ms (P200), a negative peak between 300-500 ms (N400) and a late positive component between 600-900 ms (LPC). Differences between the waveforms for the critical conditions are described below.

**Rhyming effect (RE).** Figure 30 shows the ERP waveforms elicited by all rhyming and non-rhyming conditions (forming the rhyming effect) at all 27 scalp electrode sites. This comparison is most similar to those presented in other studies evaluating the rhyming effect (RE). As in the past literature, the RE was most notable as a mean
amplitude difference between the conditions such that the non-rhyming condition elicited a larger negative waveform compared to the rhyming condition. The difference between rhyming and non-rhyming targets was biggest at about 400 ms post-target onset.

Between 300 and 900 ms, there was a significant main effect of condition for each set of electrode sites: midline: $F(1, 15) = 35.73, p = .000$; middle circle: $F(1, 15) = 32.09, p = .000$ and outer circle: $F(1, 15) = 13.53, p = .002$. The result reflects the fact that the mean amplitude of the non-rhyming targets was more negative than the mean amplitude of the rhyming targets in the 300-900 ms window post-target onset.

Furthermore, there was a significant interaction between condition and electrode over the midline: $F(4, 60) = 8.87, p = .000$. Post-hoc tests showed that there was a statistically significant mean amplitude difference between the rhyming and non-rhyming conditions at each electrode of the midline: FzA: $F(1, 15) = 18.01, p = .001$; Fz: $F(1, 15) = 18.16, p = .001$; Cz: $F(1, 15) = 49.87, p = .000$; Pz: $F(1, 15) = 60.90, p = .000$ and Oz: $F(1, 15) = 20.33, p = .000$. However, the rhyming effect was largest (i.e., there was the greatest difference between conditions) at the central and parietal midline regions. There was also a trend toward a significant interaction between condition and electrode over the middle circle: $F(5, 75) = 3.19, p = .052$.

**Rhyming conditions.**

**Consistency effect.** Figure 31 shows the waveforms elicited by rhyming consistent target words primed by inconsistent versus consistent words (forming the consistency effect) at all 27 scalp electrode sites. The consistency effect was notable as a subtle mean amplitude difference between the rhyming conditions such that the consistent target words elicited more negative waveforms when primed by inconsistent relative to
consistent words in the 300-450 ms time window, producing a negative peak at about 400 ms post-target onset (N400). Furthermore, consistent target words elicited less positive waveforms when primed by inconsistent relative to consistent words in the 450-600 ms time window, producing a negative peak at about 600 ms post-target onset (LPC).

In the 300-450 ms (N400) time window, there was a trend toward a significant interaction among condition, electrode and hemisphere over the outer circle: $F(4, 60) = 3.17, p = .074$.

In the 450-600 ms (LPC) time window, there was a significant interaction among condition, electrode and hemisphere over the outer circle: $F(4, 60) = 4.64, p = .021$.

Further 2 (experimental condition) X 5 (electrode) ANOVAs were performed to investigate the three-way interaction over each hemisphere at the outer circle sites. The effect did not reach significance over either hemisphere of the outer circle. However, the pattern of results suggests that the left hemisphere may be driving effect.

**Orthography effect.** Figure 32 shows the waveforms elicited by rhyming consistent target words primed by orthographically dissimilar relative to orthographically similar consistent words (forming the orthography effect) at all 27 scalp electrode sites. This comparison is similar to those presented in other studies evaluating the effect of orthographic similarity on rhyme judgments (e.g., Rugg & Barrett, 1987; Weber-Fox et al., 2003). The orthography effect was notable as a mean amplitude difference between rhyming conditions such that the orthographically dissimilar word pairs elicited more negative waveforms compared to the orthographically dissimilar word pairs in the 250-400 ms time window, producing a negative peak at about 400 ms post-target onset (N400). The difference between the orthographically similar and dissimilar conditions
appeared to be due to an attenuation of the N400 amplitude for the similar pairs. However, the orthographically similar word pairs generated a less positive waveform than the dissimilar pairs in the 400-600 ms window post-target onset, appearing to generate a positive peak around 600 ms post-target onset (LPC).

In the 250-400 ms (N400) time window, there was a significant main effect of condition over the midline: \( F(1, 15) = 8.26, p = .012 \) and middle circle: \( F(1, 15) = 6.67, p = .021 \). These results indicate that orthographically dissimilar rhyming word pairs (e.g., R+C+O– WHITE–FIGHT) elicit more negative amplitudes than orthographically similar rhyming word pairs (e.g., R+C+O+ RIGHT–FIGHT) in the 250-400 ms time window.

In the 400-600 ms (LPC) time window, there was a trend toward a significant interaction between condition and electrode over the midline: \( F(4, 60) = 2.95, p = .084 \) and middle circle: \( F(5, 75) = 3.06, p = .085 \).
Figure 30. Grand average event-related potentials elicited by rhyming conditions (solid lines) and non-rhyming conditions (dotted lines) from all 27 scalp electrodes. Data are plotted from 100 ms prior to the onset of the target word until 900 ms post-target onset, and negative is plotted up. The rhyming effect is observed within the 300-900 ms window post-target onset.
Figure 31. Grand average event-related potentials elicited by rhyming consistency congruent conditions (solid lines) and consistency incongruent conditions (dotted lines) from all 27 scalp electrodes. Data are plotted from 100 ms prior to the onset of the target word until 900 ms post-target onset, and negative is plotted up. The consistency effect is observed within the 300-450 ms, 450-600 ms and 750-900 ms temporal windows post-target onset.
Figure 32. Grand average event-related potentials elicited by rhyming orthographically dissimilar conditions (solid lines) and orthographically similar conditions (dotted lines) from all 27 scalp electrodes. Data are plotted from 100 ms prior to the onset of the target word until 900 ms post-target onset, and negative is plotted up. The orthography effect is observed within the 250-400 ms and 400-600 ms temporal windows post-target onset.
Non-rhyming conditions.

**Consistency effect.** Figure 33 shows the waveforms elicited by non-rhyming inconsistent target words primed by consistent versus inconsistent words (forming the consistency effect) at all 27 scalp electrode sites. An effect of consistency was not evidenced over any of the electrode sites within any of the time windows tested (N400: 400-500 ms and LPC: 550-650 ms).

**Orthography effect.** Figure 34 shows the waveforms elicited by non-rhyming inconsistent target words primed by orthographically dissimilar versus orthographically similar inconsistent words (forming the orthography effect) at all 27 scalp electrode sites. This comparison is similar to those presented in other studies evaluating the effect of orthographic similarity on non-rhyme judgments (e.g., Rugg & Barrett, 1987; Weber-Fox et al., 2003). The orthography effect was notable as a mean amplitude difference between non-rhyming conditions such that the orthographically similar word pairs elicited less negative waveforms compared to the orthographically dissimilar word pairs at the early part of the N400 (250-400 ms time window), but more negative waveforms in the later part of the N400 window (450-600 ms time window). Furthermore, a more positive LPC waveform was elicited by the orthographically similar relative to the orthographically dissimilar word pairs in the 600-900 ms temporal window post-target onset.

**Mean amplitude difference.** In the 250-400 ms (early N400) time window, there was a main effect of condition over the midline: $F(1, 15) = 18.26, p = .001$, middle circle: $F(1, 15) = 20.12, p = .000$ and outer circle: $F(1, 15) = 29.68, p = .000$. This set of results reflects the fact that the orthographically dissimilar non-rhyming condition (e.g., R–C+O– CHILD–COUGH) elicited larger negative amplitudes relative to the
orthographically similar non-rhyming condition (R–C+O+ DOUGH–COUGH) in the 250-400 ms time window.

There was also a significant interaction among condition, electrode and hemisphere over the middle circle: \( F(5, 75) = 9.23, p = .000 \) and outer circle: \( F(4, 60) = 15.21, p = .000 \). Further 2 (experimental condition) X 6 (electrode) ANOVAs were performed to investigate the three-way interaction over each hemisphere at the middle circle sites. There was a main effect of condition over the left hemisphere: \( F(1, 15) = 6.23, p = .025, \) as well as over the right hemisphere: \( F(1, 15) = 28.71, p = .000 \). Further paired samples t-tests revealed significant and trending toward significant differences between orthographically similar and dissimilar non-rhyming conditions over the left hemisphere at FA3: \( t(15) = -3.57, p = .018 \) and F3: \( t(15) = -2.77, p = .084 \) and at all electrode sites over the right hemisphere: F4A: \( t(15) = -3.81, p = .012 \); F4: \( t(15) = -3.16, p = .036 \); RT: \( t(15) = -3.21, p = .036 \); RTP: \( t(15) = -4.84, p = .000 \); P4: \( t(15) = -4.28, p = .006 \) and P4P: \( t(15) = -3.38, p = .024 \). This set of results reflects the fact that the orthography effect found in the 250-400 ms time window over the middle circle sites had a mainly right hemisphere distribution.

Further 2 (experimental condition) X 5 (electrode) ANOVAs were performed to investigate the three-way interaction over each hemisphere at the outer circle sites. There was a main effect of condition over the left hemisphere: \( F(1, 15) = 12.27, p = .003 \), as well as over the right hemisphere: \( F(1, 15) = 22.20, p = .000 \). Further paired samples t-tests revealed significant and trending toward significant differences between orthographically similar and dissimilar non-rhyming conditions over the left hemisphere at F7A: \( t(15) = -4.95, p = .000 \); F7: \( t(15) = -3.41, p = .02 \) and LAT: \( t(15) = -2.66, p = .09 \).
and over the right hemisphere at F8A: \( t(15) = -2.94, p = .050 \); F8: \( t(15) = -3.30, p = .025 \);
RAT: \( t(15) = -3.24, p = .025 \); T6: \( t(15) = -4.29, p = .005 \) and OR: \( t(15) = -3.68, p = .01 \).
This set of results suggests that the orthography effect found in the 250-400 ms time window over the outer circle sites had a right hemisphere distribution.

In the 450-600 ms (late N400) time window, there was a significant interaction between condition and hemisphere over the middle circle: \( F(1, 15) = 11.28, p = .004 \) and outer circle: \( F(1, 15) = 9.19, p = .008 \). Post-hoc analyses showed that the effect had a left hemisphere distribution over both the middle circle: \( F(1, 15) = 6.86, p = .019 \) and outer circle: \( F(1, 15) = 5.44, p = .034 \). This set of results reflects the fact that the orthographically similar non-rhyming condition (R–C+O+ DOUGH–COUGH) elicited larger negative amplitudes relative to the orthographically dissimilar non-rhyming condition (e.g., R–C+O– CHILD–COUGH) in the 450-600 ms time window.

In the 600-900 ms (LPC) time window, there was a main effect of condition that was significant over the midline: \( F(1, 15) = 4.61, p = .048 \) and that showed a trend toward significance over the middle circle: \( F(1, 15) = 4.47, p = .052 \) and outer circle: \( F(1, 15) = 3.26, p = .091 \). This set of results reflects the fact that in the 600-900 ms time window, the orthographically dissimilar non-rhyming condition (e.g., R–C+O– CHILD–COUGH) elicited less positive amplitudes relative to the orthographically similar non-rhyming condition (R–C+O+ DOUGH–COUGH). There was also a trend toward a significant interaction among condition, electrode and hemisphere over the middle circle: \( F(5, 75) = 3.17, p = .061 \) and outer circle: \( F(4, 60) = 2.79, p = .094 \).

Peak latency difference. In addition to evaluating the mean amplitude differences for the orthography effect, there appeared to be a peak latency difference such that the
orthographically dissimilar non-rhyming condition (e.g., R–C+O– CHILD–COUGH) peaked at about 350 ms post-target onset: Followed by the orthographically similar non-rhyming condition (e.g., R–C+O+ DOUGH–COUGH), which peaked at around 450 ms post-target onset. There was a significant main effect of condition over the midline: $F(1, 15) = 29.14, p = .000$; middle circle: $F(1, 15) = 56.05, p = .000$ and outer circle: $F(1, 15) = 106.21, p = .000$. This set of results reflects the fact that the orthographically similar non-rhyming pairs produced a later negative peak than the orthographically dissimilar non-rhyming pairs.
Figure 33. Grand average event-related potentials elicited by non-rhyming consistency congruent conditions (solid lines) and consistency incongruent conditions (dotted lines) from all 27 scalp electrodes. Data are plotted from 100 ms prior to the onset of the target word until 900 ms post-target onset, and negative is plotted up. An effect of consistency was not observed on the non-rhyming conditions.
Figure 34. Grand average event-related potentials elicited by non-rhyming orthographically dissimilar conditions (solid lines) and orthographically similar conditions (dotted lines) from all 27 scalp electrodes. Data are plotted from 100 ms prior to the onset of the target word until 900 ms post-target onset, and negative is plotted up. The orthography effect is observed within the 250-400 ms, 450-600 ms and 600-900 ms temporal windows post-target onset.
Discussion

Experiment 1 of Study 3 sought evidence that bilinguals with an orthographically shallow first language (L1 – Dutch) transferred reading strategies to their orthographically deep second language (L2 – English). Dutch-English bilinguals who were immersed in a Dutch-speaking environment (the Netherlands) made rhyme judgments of semantically unrelated English word pairs presented sequentially in the visual modality, while behavioral responses and event-related potentials (ERPs) were recorded. The spelling-sound consistency and orthographic similarity of rhyming and non-rhyming prime-target pairs were varied systematically. The current experiment is replication of Experiment 1 of Study 2, which tested non-native English speakers with a shallow L1 orthography (i.e., Spanish-English bilinguals) immersed in an English (L2) speaking environment. The purpose of replicating the experiment with Dutch-English bilinguals tested in the Netherlands is to investigate whether the language immersion context has an effect on bilinguals’ transfer of reading strategies from a shallow L1 to a deep L2.

Rhyming Effect

Behavioral measures indicated that rhyming targets elicited slightly faster, but equally accurate responses relative to non-rhyming targets. This pattern of reaction time results is consistent with those elicited by the English monolinguals tested in Study 1 and with the Spanish-English bilinguals tested in Study 2. However, unlike the pattern of accuracy results observed in English monolinguals, Spanish-English and Chinese-English bilinguals, the Dutch-English bilinguals did not show response accuracy facilitation for the rhyming relative to the non-rhyming conditions. Electrophysiological measures
revealed that non-rhyming targets elicited more negative N400 and less positive LPC waveforms than rhyming targets in the 300-900 ms time window. The pattern of results observed over the N400 follows the prediction and is consistent with the results elicited by Spanish-English and Chinese-English bilinguals in Study 2, suggesting that bilinguals are sensitive to L2 phonology regardless of whether they are immersed in an L1 or L2 speaking environment. Furthermore, this pattern of results replicates the rhyming effect elicited by Chinese-English bilinguals making rhyme judgment decisions about English (L2) word pairs (Chen et al., 2010). The effect is also consistent with findings reported in most previous ERP studies with native speakers using the visual rhyme-priming paradigm with letter, word and nonword stimuli in English (L1; e.g., Coch, et al., 2011; Coch et al., 2008a, b; Grossi et al., 2001; Khateb et al., 2007; Rugg, 1984a, b; Weber-Fox et al., 2003), Spanish (L1) word pairs (Perez-Abalo et al., 1994) and Chinese word pairs (L1) word pairs (Chen et al., 2010).

The N400 effect in the rhyme-priming paradigm has been hypothesized to be a mismatch-related response that occurs when the phonological representation activated by the target word differs from that of the prime word (Khateb et al., 2007; Kramer & Donchin, 1987; Rugg, 1984a). According to the spreading activation account, a reduction of the N400 is noted in response to rhyming relative to non-rhyming conditions because when participants access the phonological representation of the prime, the activation spreads automatically to phonologically related nodes, facilitating the processing of phonologically similar relative to phonologically dissimilar targets.

The more positive LPC elicited in response to rhyming relative to non-rhyming conditions may reflect increased response monitoring for the rhyming relative to the non-
rhyming conditions. The same pattern of results was noted in English monolinguals, as well as Spanish-English and Chinese-English bilinguals. As in the case of the previous two bilingual groups, the LPC elicited by Dutch-English bilinguals may be related to the attention and monitoring processes involved in making rhyme judgments in the second language.

It should be noted that the design of the study was not optimal for investigating the RE given that a different set of targets was used in the rhyming conditions (i.e., consistent target words) than in the non-rhyming conditions (i.e., inconsistent target words). That is because the study was designed specifically to evaluate the effects of spelling-sound consistency and orthographic similarity on activating phonology from print.

**Consistency Effect**

Behavioral measures of response time and accuracy showed facilitation for rhyming consistent target words primed by consistency congruent (e.g., R+C+O– WHITE–FIGHT) relative to consistency incongruent (e.g., R+C−O– HEIGHT–FIGHT) words. Electrophysiological measures revealed a trend toward a more negative N400 elicited by the consistency incongruent relative to the congruent conditions. There was also a hint of a less positive LPC elicited by the consistency incongruent relative to the consistency congruent conditions.

The fact that Dutch-English bilinguals showed a pattern of more negative N400 mean amplitudes in response to consistent targets paired with inconsistent (e.g., R+C−O– HEIGHT–FIGHT) relative to consistent (e.g., R+C+O– WHITE–FIGHT) primes may suggest that they employ more cognitive resources in processing English words with inconsistent relative to consistent spelling-sound mappings. This suggests that the N400,
which has been reported as a mismatch-related negativity that occurs in response to phonological (Khateb et al., 2007; Rugg, 1984a) and orthographic (Kramer & Donchin, 1987; Rugg & Barrett, 1987; Weber-Fox et al., 2003) dissimilarity, may also be sensitive to a mismatch in spelling-sound consistency between prime-target word pairs. Alternatively, the modulation of the N400 in response to the spelling-sound consistency manipulation may also reflect competition among friend and rival rime pronunciations (see Holcomb et al., 2002).

The LPC has been related to attention-demanding aspects of processing, such as information reanalysis for the purpose of resolving response uncertainty (e.g., Kolk & Chwilla, 2007). The fact that the LPC showed a pattern of decreased positivity in response to consistent targets paired with inconsistent (e.g., R+C–O– HEIGHT–FIGHT) relative to consistent (e.g., R+C+O– WHITE–FIGHT) primes may suggest that Dutch-English bilinguals check their response accuracy late in processing. This strategy may be related to their difficulty in correctly pronouncing the English inconsistent words. Alternatively, the reduced LPC may be related to the repetition of targets across the rhyming conditions (e.g., Van Petten, Kutas, Kluender, & Mitchiner, 1991).

The fact that neither behavioral nor electrophysiological measures showed an effect of consistency in the non-rhyming condition may suggest that bilinguals employ different response strategies in the non-rhyming relative to the rhyming conditions. It may be that they are basing their non-rhyme judgments on a visual analysis of the target to check whether its last grapheme matches that of the prime. This response strategy may be influenced by their relatively shallow L1 orthography, in which rhyming words share part or all of the rime spelling.
Within the rhyming conditions, Dutch-English bilinguals appear to transfer their expectation of spelling-sound consistency from the L1 to the L2. The fact that they show facilitation for the consistency congruent relative to incongruent rhyming pairs suggest that they may have a preference for spelling-sound consistency, or more difficulty in reading correctly English words with inconsistent spelling-sound mappings. Contrary to predictions and to the pattern of results evidenced by Spanish-English bilinguals in Study 2, Dutch-English bilinguals do not show an effect of consistency in their processing of non-rhyming word pairs. This lack of an effect within the non-rhyming conditions is difficult to interpret. It may be related to a response strategy triggered by the inconsistent targets in the non-rhyming conditions or may have been minimized by the repetition of the targets.

**Orthography Effect**

Behavioral measures of response time and accuracy revealed facilitation for rhyming consistent target words primed by (consistency congruent) orthographically similar (e.g., R+C+O+ RIGHT–FIGHT) relative to orthographically dissimilar words (e.g., R+C+O–WHITE–FIGHT). This result is consistent with the findings of Studies 1 and 2 and replicates the findings of previous studies investigating the role of orthographic similarity in visual rhyme judgments (e.g., Kramer & Donchin, 1987; Polich et al., 1983; Rugg & Barrett, 1987; Weber-Fox et al., 2003). Electrophysiological measures brought further evidence for the facilitation argument by revealing that rhyming consistent targets elicited more negative N400 (250–400 ms) mean amplitudes when primed by orthographically dissimilar relative to similar consistent words. The modulation of the N400 component is consistent with the findings of previous studies that manipulated the
degree of orthographic overlap between primes and targets within rhyming conditions (e.g., Rugg & Barrett, 1987; Weber-Fox et al., 2003). Furthermore, rhyming consistent targets elicited less positive LPC (400-600 ms) mean amplitudes when primed by orthographically dissimilar relative to similar consistent words.

The fact that the orthographically similar rhyming word pairs elicited less negative N400 amplitudes relative to orthographically dissimilar rhyming word pairs brings further evidence that the phonological and orthographic similarity between prime-target word pairs forms an additive effect that modulates the N400. This orthography effect noted over the N400 component is consistent with the effect reported in Studies 1 and 2 and with the N450 component described by Rugg and Barrett (1987).

The more positive LPC elicited in the processing of the orthographically dissimilar relative to the orthographically similar rhyming conditions reflects the fact that more cognitive resources are needed to produce a rhyme decision in response to the orthographically dissimilar relative to the orthographically similar conditions. This pattern is most likely due to the convergence of orthographic and phonological cues activated by the orthographically similar rhyming word pairs (e.g., R+C+O+ RIGHT–FIGHT) and reflects facilitation in processing the orthographically similar relative to the orthographically dissimilar (e.g., R+C+O– WHITE–FIGHT) rhyming conditions.

Behavioral measures of response time and accuracy showed inhibition for non-rhyming inconsistent target words primed by (consistency congruent) orthographically similar (R–C+O+ DOUGH–COUGH) relative to orthographically dissimilar words (e.g., R–C+O– CHILD–COUGH). This result is consistent with the findings reported in Studies 1 and 2 and replicates the findings of previous studies investigating the role of
orthographic similarity in visual rhyme judgments (e.g., Kramer & Donchin, 1987; Polich et al., 1983; Rugg & Barrett, 1987; Weber-Fox et al., 2003). Electrophysiological measures revealed that orthographically similar non-rhyming conditions elicited less negative early N400 waveforms (250-400 ms), but more negative late N400 waveforms (450-600 ms) relative to the orthographically dissimilar conditions. Furthermore, a more positive LPC (600-900 ms) waveform was elicited by the orthographically similar relative to the orthographically dissimilar conditions. This pattern of results is similar to the one elicited by English monolinguals in Study 1 and may be related to Dutch-English bilinguals’ English proficiency level.

The more negative early N400 waveform elicited by the orthographically dissimilar relative to the orthographically similar conditions may suggest that the N400 is modulated by the mismatch in phonological and orthographic cues. In the process of testing whether prime-target word pairs match in phonology, participants hold the phonological representation of the prime in working memory and compare it against the target. Since there may be a short time lag between the processing of the target’s orthography and the activation of its phonological representation (Grainger et al., 2006), the less negative late N400 waveform elicited by the orthographically similar condition suggests that participants recognize the mismatch between orthographic and phonological cues activated by the orthographically similar non-rhyming conditions.

Furthermore, the more positive LPC elicited in response to the orthographically similar relative to the orthographically dissimilar non-rhyming conditions suggests that the late stage of processing involves a reanalysis of the conflicting orthographic and
phonological information. This suggests that Dutch-English bilinguals are monitoring the accuracy of their behavioral responses.

The effect of orthography found in Dutch-English bilinguals replicates the overall pattern of results found in English monolinguals, Spanish-English and Chinese-English bilinguals, suggesting that the facilitation produced by converging phonological and orthographic cues and the inhibition produced by diverging cues is found across native and non-native readers of English. The fact that Dutch-English and Spanish-English bilinguals differ in the degree of sensitivity to the orthographic similarity between the prime-target word pairs may be related to the fact that Spanish orthography is shallower than that of Dutch (Seymour et al., 2003).

Overall, Dutch-English bilinguals’ sensitivity to English spelling-sound consistency suggests that they prefer using a small grain size when reading a deep L2 orthography, such as that of English. This set of results is similar to the findings reported in Experiment 1 of Study 2 and may reflect a reading strategy that is common across readers of a shallow L1 and deep L2 orthography regardless of their language immersion context. This interpretation is supported by previous studies reported in the literature (e.g., Dressler & Kamil, 2006; Mumtaz & Humphreys, 2001; Sasaki, 2005; Spencer & Hanley, 2003). However, the differences noted in the processing of the non-rhyming conditions across the Dutch-English and Spanish-English bilinguals could be due to a response strategy that is dependent upon the relative degree of consistency associated with their orthography.
Experiment 2: Bilinguals’ Processing of Consistency in a Cross-Linguistic Context

Method

Participants

Results are presented for 25 native speakers of Dutch (7 male; mean age = 23.7 years; age range = 18 to 42 years) from Radboud University, Nijmegen. All participants were right-handed, had normal or corrected-to-normal vision, and no history of neurological dysfunction, language or reading disorders. All were volunteers paid €30 for participating in two experimental sessions.

A total of 27 participants had initially completed the study. Data from one participant was excluded from the final analysis for achieving lower than 60% response accuracy on the overall rhyming conditions. One other participant was excluded from the study due to technical difficulties during data collection.

Participants had achieved high levels of English proficiency, but had maintained dominance in the native language, which was their primary language of instruction in school through eighth grade. Participants had no consistent exposure to English before age of 6. Using a 7-point rating system, these native Dutch speakers rated their English proficiency as averaging 6.01 (SD 0.66).

Stimuli

Stimuli were language unambiguous monosyllabic Dutch and English words matched in length across languages and in frequency within language (see Table A9 in Appendix A). English words had inconsistent sound-spelling mappings and were classified as either consistent or inconsistent in terms of spelling-sound mappings based on the Ziegler et al. (1997) norms, but varied in spelling-sound regularity. Dutch words served as primes and
English words were targets in a cross-linguistic Dutch-English rhyme judgment task. The task contained 72 Dutch primes and 288 English targets.

The English stimuli were equally divided between words with consistent spelling-to-sound mappings and words with inconsistent spelling-to-sound mappings. All Dutch primes were defined as consistent because Dutch has a relatively shallow orthography (Seymour et al., 2003) in which one letter is consistently mapped to one sound. The rhyming (R+) conditions consisted of 72 word pairs with consistent targets (R+C+, e.g., Dutch prime – English consistent target: KREET [kreɪt] – TRAIT) and 72 word pairs with inconsistent targets (R+C−, e.g., Dutch prime – English inconsistent target: KREET [kreɪt] – WEIGHT) pairs. Since all Dutch primes were consistent, these types of trials can also be considered consistency congruent and consistency incongruent respectively. The non-rhyming (R−) conditions also consisted of 72 word pairs with consistent targets (R−C+, e.g., Dutch prime – English consistent target: KREET [kreɪt] – DARK; consistency congruent) and 72 word pairs with inconsistent targets (R−C−, e.g., Dutch prime – English inconsistent target: KREET [kreɪt] – TEAR; consistency incongruent).

Table 3 summarizes the phonological and consistency manipulations used in this experiment. A key difference between the trials in this cross-linguistic rhyme priming task and the English rhyme priming task described previously is that the targets varied across conditions in this task, while the primes were the same.

Another important difference between the trials in this cross-linguistic rhyme priming task and the English rhyme priming task is that the cross-linguistic task did not include a systematic manipulation of orthographic overlap between primes and targets. Instead, the graphemic similarity (Van Orden, 1987) of prime-target pairs was measured to ensure that
orthographic information did not generally cue participants to ‘yes’ or ‘no’ responses (see Table A10 in Appendix A for the graphemic similarity values of each experimental condition). For a list of all the rhyming and non-rhyming experimental items used in this experiment, please refer to Tables A6 and A7, respectively, in Appendix A. Since the Dutch primes appeared four times in this experiment, the stimulus presentation was semi-randomized so that each two repetitions were at least 72 trials apart. Four stimulus blocks were created (A, B, C, D), each target or repeating prime appearing only once per block. The initial, second, third and fourth presentation of each target was coded distinctively so that the contribution of each block could be analyzed separately. Participants were randomly assigned to one of four presentation orders (ABCD, BCDA, CDAB, DABC).

Both rhyming and non-rhyming conditions of the Dutch-English task were normed on college-aged Dutch-English bilinguals enrolled at Radboud University, Nijmegen. A detailed description of the norming study is presented below. Students who took part in the online norming study were excluded from participating in the Dutch-English ERP experiment.

<table>
<thead>
<tr>
<th>Table 3 Dutch-English Rhyme Judgment Conditions</th>
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<td><strong>Phonology</strong></td>
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<td>Rhyme (R+)</td>
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<td>Non-rhyme (R–)</td>
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Stimulus Norming

The experimental materials used in the Dutch-English rhyme judgment task were normed on 34 native speakers of Dutch who were proficient in English (22% of participants self-rated their English proficiency as either fair or functional; 67% as either good or very good and 11% as native-like). All participants were at least 18 years old and had no history of language and/or reading impairment. Participants were recruited from the Radboud University subject pool and received class credit for their participation. Students who took part in the online norming study were excluded from participating in the Dutch-English ERP experiment, but not from participating in the English ERP experiment.

The norming study was done over the Internet by using Qualtrics Labs, Inc. software, Version 12,018 (Provo, UT), an online survey software licensed to Penn State. Participants used their personal computers to respond to the survey questions, which used a multiple-choice format. Each question contained a pair of words and participants were asked to decide whether the words rhymed or not by clicking either the “rhyme” or “do not rhyme” response choices. Only one question appeared per page and a response was mandatory before the next pair of words was presented. Each pair of words remained on the screen for 10 seconds, or until the participant made a response. The items were presented in random order. The survey took one hour to complete.

Dutch-English word pairs were labeled as ‘rhyming’ if the majority of raters responded in favor of the rhyming decision and as ‘non-rhyming’ if the majority of raters responded in favor of the non-rhyming decision. Overall, the results of the norming study
showed that the participants were able to make the decisions required for the task.
Participants rated all of the 144 non-rhyming trials as non-rhyming. Out of the 144 rhyming trials, norming study participants rated 14 trials as more likely not to rhyme and 2 trials as equally likely to rhyme or not rhyme. Out of these trials, 9 included a target word with inconsistent spelling-sound mappings (SWAP, THWART, WART, TOMB, WOMB, COMB, LIMB, TOUR, SWAM) and one included a target word with consistent mappings, but that also ended in a silent b, which proves to be difficult for non-native English speakers to pronounce (LAMB). Trials containing these words as targets were kept in the experiment, but were excluded from the analysis of the behavioral and ERP data of those participants whose responses to such trials were incorrect. However, they were left in for those who were able to correctly make the rhyming decision.

**Procedure**

Experiment 2 of Study 3 used the same procedure as Experiment 1 of Study 3 (see page 71 for a review), with the exception that the visual rhyme judgment task used Dutch-English instead of English-only word pairs. The sequence of events of the Dutch-English rhyme judgment task was previously described in the general method section (page 57). The behavioral testing session was as in Experiment 1 of Study 3, with the exception that participants’ knowledge of the English words used in the rhyme judgment task was tested with a paper and pencil task administered at the end of testing session 1, while their ability to pronounce the same words was tested using a word naming task administered at the end of session 2. Both response times and accuracy were measured on each trial.
EEG Recording Procedure

Experiment 2 of Study 3 used the electrode setup and recording procedure described on page 63.

Data Analysis

Rhyme judgment performance was evaluated using both behavioral and electrophysiological responses elicited by targets. Reaction times and accuracy rates were measured based on correct button press responses recorded within the 200-2000 ms time window. Participants’ response times and accuracy rates across rhyming and non-rhyming conditions were compared using repeated measures analysis of variance (ANOVA). The effect of spelling-sound consistency on participants’ rhyming and non-rhyming decisions (response times and accuracy rates) can be evaluated using a repeated measures ANOVA with a 2 (condition: rhyming, non-rhyming) x 2 (target word consistency: consistent, inconsistent) design due to the matching used for the current study. However, in order for the results to be more similar to those reported for the previous studies, the effects of spelling-sound consistency were evaluated using separate repeated measures ANOVAs for rhyming and non-rhyming decisions.

EEG and EOG recordings were examined for muscle artifact and eye movements/BLinks. Trials that were contaminated or that had received incorrect responses were removed from the analysis. To be included in the analyses, individual participants had to have responded accurately to at least 60 percent of rhyming and non-rhyming trials without showing a bias towards one response and to have had at least 20 artifact-free correct response trials within each of the four conditions. Separate ERP waves to rhyming
and non-rhyming targets for each of the four conditions were averaged off-line for each participant at each electrode site over a 1000 ms epoch. Averages were aligned to a 100 ms baseline preceding target onset and ended 900 ms post target onset.

The mean amplitude of the rhyming effect was calculated in the 300-800 ms time window post-target onset. In addition, smaller temporal windows were chosen based on visual observation of the grand averages to evaluate the effect of the spelling-sound consistency manipulation. Specifically, the mean amplitude of the spelling-sound consistency effect was evaluated for two windows within the rhyming conditions (300-500 ms and 500-700 ms) and one window within the non-rhyming conditions (250-350 ms).

Repeated measures ANOVAs were performed separately for the within-subject factor of spelling-sound consistency (consistent versus inconsistent targets) in rhyming and non-rhyming conditions for the midline electrode sites (FzA, Fz, Cz, Pz, Oz) and two concentric rings of lateral electrode sites (middle circle: F3A/F4A, F3/F4, LT/RT, LTP/RTP, P3/P4, P3P/P4P; outer circle: F7A/F8A, F7/F8, LAT/RAT, T5/T6, OL/OR). Hemisphere (left versus right) was included as a factor in the analyses involving lateral electrode sites.
Results

Behavioral Results

The behavioral results are shown in Figures 35 and 36. In a comparison of responses to all rhyming and all non-rhyming conditions, there was no effect of condition on respond times, but there was a significant main effect of condition on response accuracy: $F(1, 24) = 32.09, p = .000$. This result reflects the fact that Dutch-English bilinguals were equally fast in responding to rhyming and non-rhyming conditions, but more accurate in responding to non-rhyming relative to rhyming conditions. This pattern of results is consistent with that produced by Dutch-English bilinguals who completed the norming study, suggesting that it is more difficult to make rhyme relative to non-rhyme judgments of word pairs with include primes from one language and targets from a different language.

**Rhyming conditions.** There was no effect of target consistency on rhyming response times, but there was a trend toward a significant main effect of target consistency on rhyming response accuracy: $F(1, 24) = 3.67, p = .067$, indicating that Dutch-English bilinguals were equally fast, but more accurate in responding to English consistent (e.g., R+C+ KREET [kreɪt] – TRAIT) relative to English inconsistent (e.g., R+C– KREET [kreɪt] – WEIGHT) rhyming targets when primed by Dutch words. Recall that prime-target orthographic similarity was held constant across the two rhyming conditions used to evaluate the effect of consistency. This pattern of results is also consistent with that produced by Dutch-English bilinguals who completed the norming study, suggesting that Dutch speakers have difficulty in reading English words with inconsistent spelling-sound mappings. This difficulty may be related to the switching from the small grain size used
to read Dutch words to a large grain size needed to read English words with inconsistent spelling-sound mappings.

**Non-rhyming conditions.** There was no effect of target consistency on non-rhyming response times and accuracy, indicating that participants were equally fast and accurate in responding to English consistent (e.g., R–C+ KREET [kreɪt] – DARK) and inconsistent (e.g., R–C–KREET [kreɪt] – TEAR) non-rhyming targets when primed by Dutch words. Recall that prime-target orthographic similarity was held constant across the two non-rhyming conditions used to evaluate the effect of consistency.

*Figure 35.* Mean reaction times (in ms) for rhyming and non-rhyming conditions. Error bars show 95% confidence intervals.
Electrophysiological Results

The waveforms elicited during the task showed a series of peaks consistent with previous visual word recognition studies. Specifically, there was a clear negative peak around 100 ms (N100), followed by a positive peak around 200 ms (P200), a negative peak between 300-500 ms (N400) and a late positive component between 500-700 ms (LPC). Differences between the waveforms for the critical conditions are described below.

Rhyming effect (RE). Figure 37 shows the ERP waveforms elicited by all rhyming and non-rhyming conditions (forming the rhyming effect) at all 27 scalp electrode sites. This comparison is most similar to those presented in other studies evaluating the rhyming effect (RE). As in the past literature, the RE was most notable as a mean amplitude difference between the conditions such that the non-rhyming condition elicited
a larger negative waveform compared to the rhyming condition. The difference between rhyming and non-rhyming targets was biggest at about 400 ms post-target onset.

Between 300 and 800 ms, there was a significant main effect of condition for each set of electrode sites: midline: $F(1, 24) = 35.17, p = .000$; middle circle: $F(1, 24) = 29.22, p = .000$; and outer circle: $F(1, 24) = 13.66, p = .001$. The result reflects the fact that the mean amplitude of the non-rhyming targets was more negative than the mean amplitude of the rhyming targets in the 300-800 ms window post-target onset.

There was also a significant interaction between condition and electrode over the midline: $F(4, 96) = 5.47, p = .008$ and a trend toward a significant interaction between condition and electrode over the middle circle: $F(5, 120) = 3.00, p = .074$. Post-hoc tests showed a wide distribution of the effect, such that there was a significant difference in the mean amplitude of rhyming and non-rhyming conditions at each electrode of the midline: FzA: $F(1, 24) = 20.06, p = .000$; Fz: $F(1, 24) = 24.17, p = .000$; Cz: $F(1, 24) = 28.65, p = .000$; Pz: $F(1, 24) = 41.51, p = .000$; and Oz: $F(1, 24) = 33.31, p = .000$. However, the magnitude of the difference between conditions varied such that the rhyming effect was smallest over the pre-frontal and frontal sites of the midline.

Furthermore, there was a significant interaction among condition, electrode and hemisphere over the outer circle: $F(4, 96) = 4.82, p = .023$. Further 2 (experimental condition) X 5 (electrode) ANOVAs were performed to investigate the three-way interaction over each hemisphere at the outer circle sites. There was a main effect of condition over the left hemisphere: $F(1, 24) = 4.46, p = .045$, as well as over the right hemisphere: $F(1, 24) = 19.48, p = .000$. Further paired t-tests revealed significant differences between rhyming and non-rhyming conditions over the following left
hemisphere electrode sites: OL: $t(24) = 4.21, p = .000$; and over all right hemisphere sites: F8A: $t(24) = 4.56, p = .000$; F8: $t(24) = 3.93, p = .005$; RAT: $t(24) = 4.50, p = .000$; T6: $t(24) = 3.17, p = .02$; and OR: $t(24) = 3.51, p = .01$. This set of results reflects the fact that the rhyming effect had a largely right hemisphere distribution over the outer electrode sites.

**Rhyming conditions.**

**Consistency effect.** Figure 38 shows the waveforms elicited by English consistent versus inconsistent target words primed by rhyming Dutch words (forming the consistency effect) at all 27 scalp electrode sites. The consistency effect was notable as a mean amplitude difference between the rhyming conditions such that the English inconsistent target words elicited a more negative waveform than the English consistent target words when primed by Dutch words in the 300-500 ms time window, producing a negative peak at about 400 ms post-target onset (N400). Furthermore, the English inconsistent target words elicited a less positive waveform than the English consistent target words when primed by Dutch words in the 500-700 ms time window, producing a positive peak at about 600 ms post-target onset (LPC).

In the 300-500 ms (N400) time window, there was a significant main effect of condition over the midline: $F(1, 24) = 5.16, p = .032$ and middle circle: $F(1, 24) = 5.63, p = .026$. The result reflects the fact that English inconsistent target words primed by Dutch words (e.g., R+C– KREET [kreɪt] – WEIGHT) elicited a more negative mean amplitude relative to English consistent target words primed by Dutch words (e.g., R+C+ KREET [kreɪt] – TRAIT) over the midline and middle electrode sites in the 300-500 ms window post-target onset.
In the 500-700 ms (LPC) time window, there was a significant main effect of condition over the outer circle: $F(1, 24) = 4.33, p = .048$ and a trend toward a significant main effect of condition over the middle circle: $F(1, 24) = 3.07, p = .093$. This result reflects the fact that the consistency incongruent Dutch-English rhyming word pairs elicited less positive mean amplitudes relative to consistency congruent Dutch-English rhyming word pairs over the outer circle in the 500-700 ms time window.

**Non-rhyming conditions.**

**Consistency effect.** Figure 39 shows the waveforms elicited by English consistent versus inconsistent target words primed by non-rhyming Dutch words (forming the consistency effect) at all 27 scalp electrode sites. The consistency effect was notable as a mean amplitude difference between the non-rhyming conditions such that the English consistent target words primed by Dutch words elicited a more negative mean amplitude relative to the English inconsistent target words primed by Dutch words in the 250-350 ms window, constituting the early part of the negative going component (N400).

In the 250-350 ms (early N400) time window, there was a trend toward a significant main effect of condition over the midline: $F(1, 24) = 3.38, p = .079$. The difference in this window appeared to peak at 300 ms post-target onset.

There was also a significant interaction between condition and electrode over the midline: $F(4, 96) = 4.47, p = .019$ and outer circle: $F(4, 96) = 4.21, p = .041$; and a trend toward a significant interaction over the middle circle: $F(5, 120) = 3.79, p = .052$. Post-hoc analyses revealed a frontal distribution of the consistency effect, such that there was a significant or trend toward significant difference in the mean amplitude of consistency congruent (e.g., R–C+ KREET [kreɪt] – DARK) relative to consistency incongruent (e.g.,
R–C–KREET [kreɪt] – TEAR) non-rhyming conditions that was evidenced over the midline at FzA: $F(1, 24) = 4.53, p = .044$; Fz: $F(1, 24) = 5.63, p = .026$ and Cz: $F(1, 24) = 3.78, p = .064$; and over the outer circle at F7A/8A: $F(1, 24) = 4.43, p = .046$; F7/8: $F(1, 24) = 4.17, p = .052$ and LAT/RAT: $F(1, 24) = 4.50, p = .044$. 
Figure 37. Grand average event-related potentials elicited by rhyming conditions (solid lines) and non-rhyming conditions (dotted lines) from all 27 scalp electrodes. Data are plotted from 100 ms prior to the onset of the target word until 900 ms post-target onset, and negative is plotted up. The rhyming effect is observed within the 300-800 ms window post-target onset.
Figure 38. Grand average event-related potentials elicited by rhyming consistency congruent conditions (solid lines) and consistency incongruent conditions (dotted lines) from all 27 scalp electrodes. Data are plotted from 100 ms prior to the onset of the target word until 900 ms post-target onset, and negative is plotted up. The consistency effect is observed within the 300-500 ms, 500-700 ms and 700-900 ms window post-target onset.
Figure 39. Grand average event-related potentials elicited by non-rhyming consistency congruent conditions (solid lines) and consistency incongruent conditions (dotted lines) from all 27 scalp electrodes. Data are plotted from 100 ms prior to the onset of the target word until 900 ms post-target onset, and negative is plotted up. The consistency effect is observed within the 250-350 ms window post-target onset.
Discussion

Experiment 2 of Study 3 investigated whether the presence of both L1 and L2 words in the same task facilitated the transfer of consistency expectations from a shallow L1 (i.e., Dutch) to a deep L2 (i.e., English) orthography relative to L2-only reading contexts (i.e., Experiment 1 of Study 3). Dutch-English bilinguals who were immersed in a Dutch-speaking environment (the Netherlands) but studied at a University where English was the language of instruction made rhyme judgments of semantically unrelated Dutch-English word pairs presented sequentially in the visual modality, while behavioral responses and event-related potentials (ERPs) were recorded. The spelling-sound consistency of English target words was varied systematically in both rhyming and non-rhyming conditions.

Rhyming Effect

Behavioral measures showed that both rhyming and non-rhyming targets elicited equally fast responses, but that participants were overall more accurate in responding to non-rhyming relative to rhyming conditions. This pattern of results is consistent with findings reported in some previous ERP studies using the visual rhyme-priming paradigm (e.g., Coch et al., 2008b), yet inconsistent with the behavioral results elicited by the English monolingual and bilingual groups tested in the other experiments. This difference in behavioral and accuracy results noted across the English-only and Dutch-English rhyme judgment tasks may be related to the fact that making cross-linguistic rhyme judgments may be more cognitively demanding than making rhyme judgments in one’s first or second language. For this reason, non-rhyme decisions may have been facilitated in the cross-linguistic rhyme judgment task.
In contrast, electrophysiological measures revealed that non-rhyming targets elicited more negative N400 and less positive LPC waveforms than rhyming targets in the 300-800 ms time window. The pattern of results observed over the N400 is consistent with those elicited by the Spanish-English, Chinese-English and Dutch-English bilingual groups when performing the rhyme judgment task in their L2 (i.e., English). Furthermore, this pattern of results is consistent with the prediction and with findings reported in most previous ERP studies using the visual rhyme-priming paradigm with letter, word and nonword stimuli in English (L1; e.g., Coch, et al., 2011; Coch et al., 2008a, b; Grossi et al., 2001; Khateb et al., 2007; Rugg, 1984a, b; Weber-Fox et al., 2003), Spanish (L1) word pairs (Perez-Abalo et al., 1994), Chinese (L1) and English (L2) word pairs (Chen et al., 2010).

The more positive LPC elicited in response to rhyming relative to non-rhyming conditions may reflect increased response monitoring for the rhyming relative to the non-rhyming conditions. The same pattern of results was noted in English monolinguals and across the bilingual groups tested in the L2 (i.e., English). The LPC elicited by Dutch-English bilinguals performing a cross-linguistic Dutch-English rhyme judgment task may be related to the attention and monitoring processes involved in making rhyme judgments in the second language and cross-linguistically.

The current study is the first to date to report a cross-linguistic rhyming effect. The presence of a cross-linguistic rhyming effect may suggest that bilinguals are sensitive to phonological similarities between their L1 and L2. That is because a reduction of the N400, previously found in participants performing the rhyme judgment task in their L1 (see Study 1) and in their L2 (see Study 2 and Experiment 1 of Study 3), has also been
found in this cross-linguistic task. This may suggest that the activation of the phonological representations elicited by the Dutch primes spreads cross-linguistically to phonologically related nodes in bilinguals’ L2 (i.e., English). This spreading activation across bilinguals’ two languages facilitates the processing of phonologically similar relative to phonologically dissimilar English targets paired with Dutch words.

**Consistency Effect**

Behavioral measures of response accuracy showed facilitation for English consistent (e.g., TRAIT) relative to inconsistent (e.g., WEIGHT) rhyming targets when primed by Dutch words (e.g., KREET [kreɪt]). This finding was supported by electrophysiological measures, which revealed that English inconsistent targets elicited more negative N400 (300-500 ms) waveforms and less positive LPC (500-700 ms) waveforms relative to English consistent targets.

The N400 has been reported as a mismatch-related negativity that occurs in response to phonological (Khateb et al., 2007; Rugg, 1984a) and orthographic (Kramer & Donchin, 1987; Rugg & Barrett, 1987; Weber-Fox et al., 2003) dissimilarity. The larger negative amplitude elicited by the consistency incongruent trials (e.g., R+C– KREET [kreɪt] – WEIGHT) relative to the consistency congruent trials (e.g., R+C+ KREET [kreɪt] – TRAIT) suggests that greater cognitive resources may be needed to resolve a mismatch in spelling-sound consistency relative to matching spelling-sound consistency. This result may also suggest that the N400 is modulated by the mismatch in grain size across primes and targets. Alternatively, the mean amplitude difference observed over the N400 may also reflect the difficulty that Dutch-English bilinguals may have in reading English inconsistent relative to consistent words. It is hard to say with certainty whether
the modulation observed over the N400 is caused by a switch in grain size or by participants’ difficulty in reading inconsistent English words given the design of the study. However, the analysis of participants’ accuracy rates in naming the English experimental stimuli may serve as a good indicator of whether the difference in the N400 is related to pronunciation difficulty.

The LPC has been related to attention-demanding aspects of processing, such as information reanalysis for the purpose of resolving response uncertainty (e.g., Kolk & Chwilla, 2007). The fact that the consistency congruent condition (e.g., R+C+ KREET [kreɪt] – TRAIT) elicited more positive LPC waveforms relative to the consistency incongruent condition (e.g., R+C– KREET [kreɪt] – WEIGHT) suggests that Dutch-English bilinguals may pay closer attention to consistent English words late in processing in an attempt to make sure that they have activated the correct phonological representation. This strategy may be related to their difficulty in correctly pronouncing the English inconsistent words.

Behavioral measures of response time and accuracy showed that participants were equally fast and accurate in responding to non-rhyming Dutch-English word pairs regardless of the consistency of the English words. These results are consistent with Dutch-English bilinguals’ performance on the English (L2) rhyme judgment task. However, electrophysiological measures revealed that English consistent targets (e.g., DARK) elicited more negative early N400 (250-350 ms) amplitudes relative to English inconsistent targets (e.g., TEAR) when primed by non-rhyming Dutch words (e.g., KREET [kreɪt]).
The more negative N400 amplitude elicited by consistency congruent (e.g., R–C+ KREET [kreɪt] – DARK) relative to consistency incongruent (e.g., R–C–KREET [kreɪt] – TEAR) non-rhyming conditions may suggest that participants were facilitated by the prime-target grain size mismatch in making non-rhyme decisions. The difficulty in activating the phonological representation of inconsistent English words may have made word pairs containing such mismatch in grain size easier to label as non-rhyming.

The consistency effect observed across the rhyming and non-rhyming conditions suggest that bilinguals whose L1 orthography is more transparent than their L2 orthography may experience a processing cost when switching from a small grain size, associated with a shallow orthography (i.e., Dutch), to a large grain size, associated with a deep orthography (i.e., English). This cost is triggered by the mismatch in spelling-sound consistency between prime-target word pairs. The direction of the effect is difficult to interpret because it differs across rhyming and non-rhyming conditions. This difference may be related to a response strategy, such that Dutch-English bilinguals find it easier to judge Dutch-English word pairs as non-rhyming when they contain an inconsistent relative to a consistent English target.

**General Discussion**

The cost experienced by Dutch-English bilinguals in switching between consistent relative to inconsistent words in both L2 (English) and mixed (Dutch-English) language contexts suggest that they transfer an expectation of spelling-sound consistency from the L1 to the L2 in both language contexts. This pattern of results suggests a co-activation of bilinguals’ knowledge of Dutch (L1) spelling-sound correspondences when reading English (L2). This may be due to the shared Latin alphabetic script across the two
languages (e.g., Melby-Lervag & Lervag, 2011), which has been reported to facilitate bilinguals’ transfer of orthographic processing skills from the L1 to the L2 (e.g., Cárdenas-Hagan et al., 2007; Sun-Alperin, & Wang, 2011). The cost associated with the cross-linguistic transfer of reading strategies from a shallow to a deep orthography comes from the fact that bilinguals apply a small grain size to a deep orthography, which results into the mispronunciation of inconsistent words. This preference for spelling-sound consistency in a deep L2 orthography found in Dutch-English bilinguals is consistent with the findings reported by Botezatu and colleagues (in preparation) and suggests that bilinguals’ L2 language dominance is a factor that influences the observed pattern of results.
Chapter 7

General Discussion

The series of five experiments described here sought to investigate the reading strategies adopted in response to English spelling-sound consistency by English monolinguals (Study 1), bilinguals whose L1 differed in orthographic depth from English (L2) and who were tested in a L2-only context in the U.S. (Study 2: Spanish-English and Chinese-English bilinguals) and bilinguals with shallow L1 and deep L2 orthographies who were tested either in a L2-only or mixed language context in the Netherlands (Study 3: Dutch-English bilinguals). Studies 1 and 2 also investigated readers’ expectation of convergence between orthographic and phonological cues as a function of the degree of spelling-sound consistency associated with the target language (i.e., English) and the relative transparency of their L1 orthography. Previous behavioral studies have reported facilitation in the processing of English consistent relative to inconsistent words by English monolinguals (e.g., Jared et al., 1990; Jared, 1997; Lacruz & Folk, 2004; Stone et al., 1997) and Spanish-English bilinguals (Botezatu et al., in preparation). However, the electrophysiological signature of the consistency effect has never been studied in English independently of the interaction between orthographic and phonological cues in rhyme judgment tasks (but see Hsu et al., 2009 and Lee et al., 2007 for an investigation of the temporal dynamics of the print-to-sound consistency effect in Chinese). More specifically, studies using the visual rhyme judgment paradigm to evaluate the degree of reliance on orthographic cues in judging the phonological similarity of word pairs (e.g., Polich et al., 1983; Rugg & Barrett, 1987; Weber-Fox et al., 2003) have confounded their manipulations of orthographic and phonological cues with a manipulation of spelling-
sound consistency, such that word pairs containing converging cues from orthography and phonology relied on consistent word bodies (e.g., SOFT – LOFT), whereas word pairs that contained diverging cues from orthography and phonology relied on inconsistent word bodies (e.g., DULL – PULL). The present set of studies manipulated three factors: 1) the spelling-sound consistency of prime and target words while holding constant the degree of orthographic similarity found in the word pairs compared; 2) the degree of orthographic similarity between prime and target words while holding constant the degree of spelling-sound consistency found in the word pairs compared and 3) the phonological similarity of word pairs in such a way that consistency and orthography effects were evaluated either across rhyming word pairs or non-rhyming word pairs. This way the time course of processing spelling-sound consistency and orthographic similarity could be evaluated in both rhyming and non-rhyming conditions. In the experiments described here, the processing of visually presented rhyming and non-rhyming prime-target word pairs containing manipulations of spelling-sound consistency and orthographic similarity was compared across monolingual and bilingual groups while behavioral and electrophysiological measures of processing were collected. It was hoped that the evaluation of both behavioral and electrophysiological correlates of processing spelling-sound consistency and orthographic similarity elicited by English monolinguals and non-native English speakers that varied in the transparency of their L1 orthography, would lead to a better understanding of the series of processes underlying the cross-linguistic transfer of reading unit size. In this chapter, the major findings of the five experiments described in this dissertation will be summarized and compared in order to find the general pattern of the electrophysiological signatures associated with the
rhyming, consistency and orthography effects across participant groups. Following these comparisons, a set of factors that distinguish bilingual from monolingual visual word recognition will be proposed for future Connectionist models of reading to take into account when designing a Connectionist model of bilingual word reading. Future directions will then be proposed.

**Phonological Processing Across L1, L2 and Mixed Language Contexts**

The use of the visual rhyme judgment paradigm in this set of studies provided the opportunity to replicate the rhyming effect previously identified in English (e.g., Coch, et al., 2011; Coch et al., 2008a, b; Grossi et al., 2001; Khateb et al., 2007; Rugg, 1984a, b; Weber-Fox et al., 2003) and Spanish monolinguals (Perez-Abalo et al., 1994), as well as in Chinese-English bilinguals performing the task in Chinese (L1) and English (L2; Chen et al., 2010). The studies employing an English rhyme judgment task found that English monolinguals, Spanish-English, Dutch-English and Chinese-English bilinguals elicited more negative-going N400 waveforms to non-rhyming than rhyming targets and more positive-going LPC waveforms to rhyming than non-rhyming targets. The behavioral measures followed the direction of the N400 component, presenting longer latencies (in English monolinguals and Spanish-English bilinguals) and decreased accuracy levels (in English monolinguals, Spanish-English and Chinese-English bilinguals) for non-rhyming relative to rhyming trials. Furthermore, the study employing a cross-linguistic Dutch-English rhyme judgment task found that Dutch-English bilinguals elicited more negative-going N400 waveforms to non-rhyming than rhyming English targets primed by Dutch words and more positive-going LPC waveforms to rhyming than non-rhyming English
targets primed by Dutch words. The behavioral measures followed the direction of the LPC component, presenting increased accuracy levels for the non-rhyming conditions.

These findings are consistent with the literature that defines the rhyming effect as an index of phonological processing reflecting a postlexical test of phonological congruency between primes and targets (e.g., Praamstra et al., 1994; Rugg & Barrett, 1987). The phonological congruency account has been originally proposed as an interpretation of the rhyming effect found in English monolinguals (Rugg & Barrett, 1987). According to this interpretation, targets that are phonologically congruent with their primes (i.e., rhyming trials) require less processing than targets that are phonologically incongruent with their primes (i.e., non-rhyming trials). This difference in cognitive resources required in the processing of rhyming and non-rhyming trials is reflected in the ERP waveform generated by each condition. This interpretation may be extended to bilinguals’ processing of rhyming versus non-rhyming conditions in their L2 and across their L1 and L2. The fact that the rhyming effect found in monolinguals has been replicated in bilinguals immersed in an L2 language context (Spanish-English and Chinese-English bilinguals) and an L1 language context (Dutch-English bilinguals, who were tested in their L2 or on a cross-linguistic task) may suggest that the congruency detection mechanism involved in making judgments of phonological similarity is common across languages. This interpretation agrees with the proposal put forward by Chen and colleagues (2010) that there may be a common neural network used in the phonological processing of L1 and L2 words. A shared rhyme detection mechanism across bilinguals’ L1 and L2, along with the co-activation of bilinguals’ two languages, may explain
bilinguals’ ability to make rhyme judgments involving overtly co-activated phonological representations of Dutch (L1) and English (L2) words.

The hypothesis of a shared rhyme detection mechanism across the L1 and L2 can be tested using the rhyme judgment data from Spanish-English and Chinese-English bilinguals. These data show that bilinguals produce a rhyming effect in their L2 regardless of the depth of their L1 orthography. Additional analyses are needed to examine whether the rhyming effect observed in the L2 differs in magnitude across bilingual groups as a function of the transparency of their L1 orthography. Such analyses could indicate whether the orthographic depth of the L1 modulates the rhyme detection process employed in the L2. If the rhyming effect found in the L2 changes in response to L1 orthographic depth, then the two languages share the rhyme detection mechanism. In this case, the mechanism has most likely been shaped by the characteristics of the L1 and transferred to the L2. If the L2 rhyming effect is not modulated by L1 orthographic depth, then the rhyme detection mechanism employed in the L2 may be distinct from the mechanism employed by the L1.

**Processing Spelling-Sound Consistency in an L2 with Distinct Orthographic Depth from the L1**

The preference for consistent spelling-sound mappings in making visual rhyme judgments of English prime-target word pairs was evaluated across Spanish-English, Dutch-English and Chinese-English bilingual groups and English monolingual controls. Electrophysiological measures showed that within the rhyming conditions, the spelling-sound consistency manipulation modulated the mean amplitude of early components
associated with visual analysis (P200 in Chinese-English bilinguals), the interface of small and large grain sizes (N250 in Spanish-English bilinguals) and lexical access (N400 in English monolinguals and Spanish-English, Dutch-English and Chinese-English bilinguals), as well as the mean amplitude of a late component associated with the conscious monitoring of response accuracy (LPC in Spanish-English, Dutch-English and Chinese-English bilinguals). The modulation of the ERP components suggested that overall, less cognitive resources were employed in making rhyming decisions involving consistent targets paired with consistent relative to inconsistent primes. Behavioral results followed the same pattern, showing that when responding to consistent (rhyming) targets, all participant groups, except Chinese-English bilinguals, were facilitated by consistent rather than inconsistent primes in making rhyme decisions.

Within non-rhyming conditions, the spelling-sound consistency manipulation also modulated the mean amplitude of early components associated with visual analysis (P200 in Chinese-English bilinguals), the interface of small and large grain sizes (N250 in Spanish-English bilinguals) and lexical access (N400 in English monolinguals, Spanish-English and Chinese-English bilinguals), as well as the mean amplitude of a late component associated with the conscious monitoring of response accuracy (LPC in Spanish-English and Chinese-English bilinguals). The modulation of the ERP components suggested that English monolinguals employed less cognitive resources in making non-rhyming decisions involving an inconsistent target paired with a consistent relative to an inconsistent prime, whereas all but Dutch-English bilinguals showed the opposite direction of the effect. Behavioral results followed the same pattern, showing that when responding to inconsistent (non-rhyming) targets, Spanish-English and
Chinese-English bilinguals were facilitated by consistent rather than inconsistent primes in making non-rhyme decisions, whereas English monolinguals were facilitated by inconsistent primes. Dutch-English bilinguals showed no effect. This difference in the pattern of results observed between the monolingual and bilingual groups suggests that the response strategy employed by the bilingual groups reflect processing in the second language.

The pattern of results observed in both rhyming and non-rhyming conditions across the monolingual and bilingual participants groups reflects the fact that English monolinguals were skilled at switching between English words with consistent and inconsistent spelling-to-sound mappings, whereas bilinguals encountered difficulty in processing inconsistent spelling-sound mappings in their L2 (English). More specifically, the overall pattern of the ERP data showed a small modulation of the N400 in response to the consistency manipulation in English monolinguals, suggesting that monolinguals were briefly affected by the competition between friend and rival pronunciations at the lexical level. In contrast, bilinguals experienced pre-lexical activation (N250 in Spanish-English bilinguals and P200 in Chinese-English bilinguals), followed by lexical activation (N400) and conscious response monitoring related to decision effort (LPC). The modulation of pre-lexical, lexical and decision-related ERP components in response to bilinguals’ processing of inconsistent spelling-sound mappings in their L2 (English) suggest a slowing down of bilinguals’ processing relative to monolinguals. Furthermore, the fact that both Spanish-English and Chinese-English bilingual groups elicit early ERP components associated with sub-lexical processing and show sensitivity to consistency in their behavioral responses suggest that they may have adopted a small grain size in
reading English (for a detailed explanation of why this may be the case, please refer to the general discussion for Study 2 on page 190). Furthermore, the fact that ERP components associated with both sub-lexical and lexical processes are modulated by consistency in these two bilingual groups may suggest that when an incorrect prime pronunciation is generated through the use of a small grain early in processing, bilinguals may experience competition at the lexical level from the orthographic neighborhood of rival (but correct) pronunciation(s) of the rime. As a result of this competition, bilinguals are slowed down, but are able to respond correctly. The rate of correct responses obtained through this process may depend on the relative frequency of the friend and rival pronunciations of a certain rime in the lexical neighborhood that bilinguals build as a result of their L2 experience and proficiency.

Moreover, bilinguals’ response latencies and accuracy rates appeared to be modulated by the orthographic distance between their L1 and L2, such that Chinese-English bilinguals were overall slower and less accurate in their responses than Spanish-English bilinguals. However, further analyses are needed to confirm this observation.

The fact that the Dutch-English bilinguals performing the English task or the Dutch-English rhyme judgment task do not show an effect of consistency over the early ERP components associated with sub-lexical processing does not mean that they are not sensitive to spelling-sound consistency. Instead, this may be related to the fact that Dutch-English bilinguals have a relatively shallow L1 (i.e., Seymour et al., 2003) and that both Dutch and English share a common German root. Therefore, they may be using a relatively larger grain size than Spanish-English bilinguals. Alternatively, Dutch-English bilinguals may be more proficient in English than Spanish-English bilinguals.
Spelling-Sound Consistency and the Competition Between Conflicting Orthographic and Phonological Cues

The ability to resolve the competition between conflicting orthographic and phonological cues in making visual rhyme judgments was evaluated across Spanish-English, Dutch-English and Chinese-English bilingual groups and English monolingual controls. Behavioral results showed that all participant groups experienced facilitation in responding to orthographically similar rhyming trials relative to orthographically dissimilar rhyming trials and inhibition in responding to orthographically similar non-rhyming trials relative to orthographically dissimilar non-rhyming trials. This pattern of results replicates previous accounts of orthography-phonology match/mismatch processing in English monolingual children (e.g., Weber-Fox et al., 2003), adults (e.g., Polich et al., 1983; Rugg & Barrett, 1987; Weber-Fox et al., 2003) and dyslexic adolescent readers (e.g., McPherson, Ackerman, & Dykman, 1997).

Electrophysiological measures revealed a larger N400 mean amplitude followed by a larger LPC mean amplitude in response to orthographically dissimilar relative to the orthographically similar rhyming conditions. This pattern of results was consistent across all participant groups, with the exception of Spanish-English bilinguals, who did not show a mean difference between conditions on the LPC. This pattern of results reveals the process through which participants make rhyme judgments of visual, sequentially presented word pairs that have in common the spelling of the rime. The initial step in judging whether the phonological representation activated by the target matches the phonology of the prime is to activate the phonological representation associated with the prime and hold it in working memory until the target is presented (e.g., Khateb et al.,
2007). Once the phonology of the prime is activated, participants test this phonological representation against the target to check whether they match. Since orthography may be activated slightly before phonology (Carreiras, Perea, Vergara, & Pollatsek, 2009; Grainger et al., 2006), participants may use the orthography of the target available to them during the early stages of visual processing to predict whether it would map onto the phonological representation needed to produce a rhyme or not. This strategy works very well when both primes and targets share the spelling of a consistent rime. In that case, participants may reach the rhyme decision before the phonology of the target is fully activated. Participants can further check their decision against the fully activated phonology of the target to confirm whether their hypothesis was correct. This process produces the behavioral response facilitation effect observed across all the participant groups in processing orthographically similar relative to dissimilar rhyming trials.

Spanish-English bilinguals do not double-check phonology before making their decision on the basis of orthographic similarity because they may transfer the expectation of spelling-sound consistency from their shallow L1 orthography. However, the fact that Dutch-English bilinguals do not rely solely on orthographic similarity in making their decision may reflect the fact that Dutch orthography is relatively deeper than Spanish orthography and that the expectation of L2 spelling-sound consistency is modulated by the relative depth of the L1 orthography.

Electrophysiological measures revealed a larger N400 mean amplitude followed by a larger LPC mean amplitude in response to orthographically dissimilar relative to the orthographically similar non-rhyming conditions. This pattern of results was consistent across Spanish-English and Chinese-English bilinguals, but the LPC showed the opposite
direction in English monolinguals and Dutch-English bilinguals. Based on the overall pattern of results, it appears that participants tried to employ the same response strategy across rhyming and non-rhyming conditions. However, the response strategy employed in the rhyming conditions was ineffective when prime-target word pairs shared an inconsistent rime, forming non-rhyming trials. In this case, participants reached an incorrect decision based on the expectation of spelling-sound consistency that created an initial incorrect response. This incorrect response was checked against the phonological representation of the target as soon as it become available and the response was corrected. The activation of the correct phonological representation of the target required more cognitive resources in the non-rhyming conditions that shared the spelling of the rime compared to the orthographically dissimilar non-rhyming conditions because the interference caused by orthographic similarity had to be inhibited.

Steps Toward a Connectionist Model of Bilingual Word Recognition

The major findings of the current dissertation were that L1-dominant bilinguals transferred spelling-sound consistency expectations from the L1 to the L2 when the two orthographies at their disposal shared the same alphabetic script. In contrast, when their L2 orthography used a different script from their L1 orthography, bilinguals’ expectation of consistency in the L2 resulted from the observed differences between the two scripts. Furthermore, the results of the set of studies conducted in this dissertation also suggested that bilinguals were sensitive to the competition between friend and rival pronunciations within the L2. This finding is consistent with previous studies (Jared & Kroll, 2001; van Leerdam et al., 2009), which found that bilinguals were sensitive to the pronunciation of
word-body rivals in the L1 when reading in the L2. This set of results helps identify a
target. This set of results helps identify a
number of factors that Connectionist models of reading should account for in modeling
bilinguals’ visual word recognition in the L2.

First of all, given that bilinguals have two sets of spelling-to-sound mappings at their
 disposal, each set belonging to one of their languages, a Connectionist model of bilingual
word recognition should account for both spelling-sound mappings systems. The model
should first distinguish whether the bilingual’s two languages share the same writing
system of not. If the L1 uses a different writing systems than the L2, then less cross-
linguistic transfer and competition is expected from the L1, so the weights between the
two systems would be weaker than between two writing systems that share the same
writing system. If the two writing systems were alphabetic, then one orthography unit
would be shared across the bilinguals’ two systems. However, the script is an important
factor to be considered here. One unit representing orthography would be ideal when the
two alphabetic orthographies share the same script (e.g., Latin alphabet), but two
orthography units may be necessary represent shared and distinct graphemes when the
two alphabetic orthographies used different scripts (e.g., Latin versus Cyrillic alphabets).
The number of shared and distinct graphemes across the two alphabetic systems and the
degree to which the shared graphemes map to the same phoneme across the two
languages is expected to modulate the competition and cross-linguistic transfer across the
two systems.

When the L1 and L2 orthographies share the same script, then transfer of spelling-
sound mappings from the L1 to the L2 is expected, with convergence across the
graphemes (typically consonants) that map to similar phonemes across the two systems,
and competition among the graphemes (typically vowels) that map to distinct phonemes in the L1 and the L2. For this reason, the orthographic depth associated with each of the two alphabetic systems must be set. Training the model on words from each of the two alphabetic systems might help set the appropriate grain size corresponding to each language. When the model is trained on two alphabetic orthographies sharing the same script that differ in orthographic depth, it should show a preference for consistency when tested in the deep orthography because the consistent mappings associated with the shallow orthography and the consistent words also present in the deep orthography may provide a more reliable cue than the inconsistent mappings associated with the deep orthography. However, increasing the model’s experience with the inconsistent mappings is likely to change this pattern.

Furthermore, given that the degree of cross-linguistic transfer is modulated by language dominance, a Connectionist model of bilingual word recognition should account for language dominance in bilinguals. This may be done by training the model on more words in one language (i.e., L1) relative to the other language (i.e., L2). Then the model may be tested on reading in the L2 to investigate the degree to which the strategies associated with each of the two languages would be employed. Spreading activations across the two languages and within the L2 are expected to occur. If a given spelling pattern is common across the two languages, then rival pronunciations from the L1 are expected to be co-activated along with rival and friend pronunciations from the L2. The strength of the competitors would depend on the strengths of connections between the orthography and phonology units within the L2 and across the L1 and L2.
**Future Directions**

Future studies should seek to further examine the reading strategies that bilinguals employ in their second language as a result of the orthographic distance between their two languages. One approach would be to rerun the analysis including only the most proficient L1-dominant Spanish-English and Chinese-English bilingual groups to test whether the same pattern of results would be observed. If the pattern of results would not change, that would exclude English proficiency as a potential confounding variable in the current results. Furthermore, the same experiment could be rerun with L2-dominant Spanish-English and Chinese-English bilingual groups to investigate whether the results change as a function of language dominance. Moreover, if access to the population would not be a concern, the experiment could be rerun with Danish-English bilinguals, who have a relatively deep L1 alphabetic orthography. Such experiment would eliminate writing system as a confounding variable in the performance comparison across Spanish-English and Chinese-English bilinguals and would further help clarify whether the sensitivity to English spelling-sound inconsistency evidenced by Chinese-English bilinguals is due to the difference in orthographic depth or in writing system between Chinese and English. Future studies should also vary systematically the syllabic complexity of bilinguals’ first language, which has been shown to co-vary along with orthographic complexity (Seymour, 2008).

Furthermore, the analyses of the ERP data could be rerun after time-locking the ERP epochs to the presentation of the prime instead of the target to investigate whether primes were processed differently as a result of their spelling-sound consistency. Additionally, the analysis of the secondary behavioral measures collected for each group (i.e.,
participants’ familiarity with the experimental English words, their reading ability and overall proficiency in the L1 and L2) might provide a more complete picture of the English reading strategies that participants have employed.

Several other experimental manipulations would also advance the current understanding of the issues investigated here. The current set of studies operationalized words as consistent when all their lexical neighbors had similar pronunciations and as inconsistent when some of their lexical neighbors had similar pronunciations, while others had rival pronunciations. The number and relative frequency of the rival pronunciations were not measured. However, the ratio and frequency of friends to enemies has been found to modulate the size of the consistency effect in monolinguals (Balota & Ferraro, 1993; Jared, 1997; 2002; Jared, McRae, & Seidenberg, 1990; Kay & Bishop, 1987). For this reason, future studies should manipulate the number and frequency of intra-lingual friends and enemies of the stimuli presented in order to test whether bilinguals also have more difficulty in processing inconsistent English (L2) words that have a high number and/or high frequency of enemies relative to friends. Furthermore, since bilinguals’ two languages are co-activated in processing, future studies should further manipulate the number and frequency of word body enemies from the non-target language (see Jared & Kroll, 2001; van Leerdam et al., 2009 for examples of such manipulations) and evaluate their effect on bilinguals’ processing of English consistent words in a task that requires covert phonological processing, such as a visual rhyme judgment task, using both behavioral and electrophysiological measures. This way a consistency effect may be induced cross-linguistically in the L2. Future studies should also manipulate the consistency of individual syllables in English bisyllabic words (see
Chateau & Jared, 2003; Jared & Seidenberg, 1990 for examples of such manipulations) to evaluate the time course of processing spelling-sound consistency in disyllabic words. While such investigations give rise to other issues, such as controlling for syllable stress, they would improve the current understanding of the role of syllable units in mediating the processing of spelling-sound consistency in bilinguals as a function of the L1 orthographic depth and in English monolingual controls.

Several other experimental paradigms may also be used to evaluate bilinguals’ grain size preference in the L2. While a naming task in which participants read aloud consistent and inconsistent words blocked by condition, or a grain size priming paradigm (see Zevin & Balota, 2000 for an example) may be obvious first choices when behavioral measures are used, their overt naming requirement constitutes a disadvantage, since it introduces muscle artifact in the recording of brainwaves. While a verbal response delay may solve this problem, it may make response times and accuracy levels more difficult to interpret. A lexical decision task, known as a “nonphonological task” (e.g., Berent, 1997) may appear to be a risky choice when evaluating spelling-sound consistency. Behavioral measures of spelling-sound regularity have yielded no evidence in lexical decision tasks (e.g., Berent, 1997; Coltheart, et al., 1979), suggesting that lexical decisions are driven by orthographic information since phonological representations are slower to activate. However, this Dual Route view of lexical access measured assembled phonology (i.e., regularity), which assumes a smaller grain size than consistency. Furthermore, a lexical decision task that contains real words and legal nonwords in the bilinguals’ two languages, along with language-ambiguous words (i.e., cognates), discourages bilinguals from making a lexical decision based on orthographic information alone. Moreover, the
use of electrophysiological measures may reveal early processes that are hidden by the behavioral data.

The studies presented in this dissertation have investigated bilinguals’ preference for spelling-sound consistency as a function of the degree of transparency associated with their L1. While these studies have evaluated the performance of highly proficient L1-dominant non-native English speakers, it is important for future studies to investigate non-native English learners’ implicit learning of reading units in their second language in order to gain a better understanding of the cross-linguistic transfer of spelling-sound consistency expectations from the L1 to the L2 as a function of the orthographic distance between the two languages. Such studies should target intermediate level English learners living in an L1-immersion context. A training phase including 10-12 one-hour long individual sessions should be provided, in which English monosyllabic consistent and inconsistent words would be presented sequentially on a computer screen followed by their correct pronunciation. Participants would be asked to type in each word and pronounce it, feedback being provided after each trial. Through repeated exposures to English monosyllabic words containing consistent and inconsistent rimes, participants should start to form a network of friend and enemy pronunciations for the rimes presented. Following the initial baseline measure, participants’ reading performance may be tested midway and at the end of the training phase using word stimuli on which they have not been trained. Participants’ performance should be evaluated using both behavioral and electrophysiological measures. Such study would provide a longitudinal measure of English language learners’ ability to adjust the size of their reading unit in response to the orthographic depth of their L2.
Conclusions

The current work evaluated how differences in orthographic depth between bilinguals’ first and second languages impact reading in an orthographically deep second language (i.e., English). Through a series of experiments that used both behavioral and electrophysiological measures, the processing of English words with consistent versus inconsistent spelling-sound mappings was evaluated across English monolinguals, Spanish-English and Chinese-English bilinguals tested in a L2-only context in the U.S. and Dutch-English bilinguals tested either in a L2-only or mixed language context in the Netherlands. The results of these studies tend to support previous claims that cross-linguistic transfer of reading strategies is facilitated when bilinguals’ two languages share the same script, regardless of the language immersion context. However, contrary to previous claims that readers of an L1 logographic script would adopt a large grain size in reading an alphabetic L2, the current work found that they employed a small grain size in reading English, just like the other bilingual groups tested in this dissertation. This pattern of results may suggest that bilinguals whose L1 orthographic system was less transparent then the one employed by their L2 judged English (L2) spelling-sound mappings as being more consistent in comparison with their L1. Overall, the reading strategies employed by the various bilingual groups tested in this dissertation seem to suggest that L1-dominant bilinguals approach reading in their L2 with a set of predictions about the consistency of its spelling-to-sound mappings based on the degree of similarity or difference across the two writing systems.
APPENDICES
APPENDIX A

English Rhyme Judgment Task Stimuli of Studies 1 and 2 and Experiment 1 of Study 3


<table>
<thead>
<tr>
<th>Pair No.</th>
<th>Consistent prime – consistent target, orthographically similar word pairs (C+O+)</th>
<th>Consistent prime – consistent target, orthographically dissimilar word pairs (C+O–)</th>
<th>Inconsistent prime – consistent target, orthographically dissimilar word pairs (C–O–)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>FAIR–CHAIR</td>
<td>HEIR–CHAIR</td>
<td>SWEAR–CHAIR</td>
</tr>
<tr>
<td>2</td>
<td>MUCH–SUCH</td>
<td>CLUTCH–SUCH</td>
<td>TOUCH–SUCH</td>
</tr>
<tr>
<td>3</td>
<td>BLOOM–GLOOM</td>
<td>FLUME–GLOOM</td>
<td>WHOM–GLOOM</td>
</tr>
<tr>
<td>4</td>
<td>BEST–ZEST</td>
<td>DRESSED–ZEST</td>
<td>BREAST–ZEST</td>
</tr>
<tr>
<td>5</td>
<td>PLAY–SAY</td>
<td>SLEIGH–SAY</td>
<td>GREY–SAY</td>
</tr>
<tr>
<td>6</td>
<td>GRIEF–THIEF</td>
<td>REEF–THIEF</td>
<td>LEAF–THIEF</td>
</tr>
<tr>
<td>7</td>
<td>TRUE–GLUE</td>
<td>WOO–GLUE</td>
<td>STEW–GLUE</td>
</tr>
<tr>
<td>8</td>
<td>JERK–CLERK</td>
<td>MURK–CLERK</td>
<td>SMIRK–CLERK</td>
</tr>
<tr>
<td>9</td>
<td>LEWD–SHREWD</td>
<td>PRUDE–SHREWD</td>
<td>FOOD–SHREWD</td>
</tr>
<tr>
<td>10</td>
<td>CREEK–SEEK</td>
<td>SHRIEK–SEEK</td>
<td>BLEAK–SEEK</td>
</tr>
<tr>
<td>11</td>
<td>COAL–FOAL</td>
<td>WHOLE–FOAL</td>
<td>TOLL–FOAL</td>
</tr>
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<td>12</td>
<td>FRUIT–SUIT</td>
<td>CUTE–SUIT</td>
<td>ROOT–SUIT</td>
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<td>SPITE–KITE</td>
<td>LIGHT–KITE</td>
<td>HEIGHT–KITE</td>
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<td>HUE–SUE</td>
<td>FLU–SUE</td>
<td>SHOE–SUE</td>
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<td>15</td>
<td>DIM–TRIM</td>
<td>HYMN–TRIM</td>
<td>LIMB–TRIM</td>
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<td>16</td>
<td>SKATE–HATE</td>
<td>BAIT–HATE</td>
<td>FREIGHT–HATE</td>
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<td>TWEEZE–SNEEZE</td>
<td>FRIEZE–SNEEZE</td>
<td>CHEESE–SNEEZE</td>
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<td>18</td>
<td>MURK–LURK</td>
<td>PERK–LURK</td>
<td>WORK–LURK</td>
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<td>CLEAN–MEAN</td>
<td>SCENE–MEAN</td>
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<td>20</td>
<td>STORE–CHORE</td>
<td>DOOR–CHORE</td>
<td>POUR–CHORE</td>
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<td>Pair No.</td>
<td>Consistent prime – consistent target, orthographically similar word pairs (C+O+)</td>
<td>Consistent prime – consistent target, orthographically dissimilar word pairs (C+O–)</td>
<td>Inconsistent prime – consistent target, orthographically dissimilar word pairs (C–O–)</td>
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<td>SNORE–SHORE</td>
<td>NOR–SHORE</td>
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<td>THIRD–BIRD</td>
<td>CURD–BIRD</td>
<td>HEARD–BIRD</td>
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<td>POND–FOND</td>
<td>BLONDE–FOND</td>
<td>WAND–FOND</td>
</tr>
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<td>24</td>
<td>CRY–DRY</td>
<td>TIE–DRY</td>
<td>HI–DRY</td>
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Rhyming Conditions (R+)
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Table A2. English Rhyme Priming Task Non-Rhyming Conditions: Experimental Items.

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### Non-rhyming Conditions (R–)

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*^Mean values based on the Kucera & Francis, 1967 norms
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*Mean graphemic similarity values based on Van Orden, 1987
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Dutch-English Rhyme Judgment Task Stimuli of Study 3, Experiment 2

**Table A6. Dutch-English Rhyme Priming Task**

*Rhyming Conditions: Experimental Items.*

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**Table A7.** Dutch-English Rhyme Priming Task Non-Rhyming Conditions: Experimental Items.
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<td>STROOM–MOUTH</td>
</tr>
<tr>
<td>33</td>
<td>LEEN–KEEP</td>
<td>LEEN–LEAST</td>
</tr>
<tr>
<td>34</td>
<td>FRIET–RINSE</td>
<td>FRIET–FOUR</td>
</tr>
<tr>
<td>35</td>
<td>VLEES–SALE</td>
<td>VLEES–CEASE</td>
</tr>
<tr>
<td>36</td>
<td>WEES–SEEK</td>
<td>WEES–SEW</td>
</tr>
<tr>
<td>37</td>
<td>HEES–SPEED</td>
<td>HEES–CHEESE</td>
</tr>
<tr>
<td>38</td>
<td>MEES–FEET</td>
<td>MEES–MOVE</td>
</tr>
<tr>
<td>39</td>
<td>VREES–SWEEP</td>
<td>VREES–VOW</td>
</tr>
<tr>
<td>40</td>
<td>ZIEK–SEIZE</td>
<td>ZIEK–QUIRK</td>
</tr>
<tr>
<td>41</td>
<td>KLIK–FLIGHT</td>
<td>KLIK–KNEW</td>
</tr>
<tr>
<td>42</td>
<td>STOEL–STUFF</td>
<td>STOEL–FEAST</td>
</tr>
<tr>
<td>43</td>
<td>BOEL–MOLD</td>
<td>BOEL–POLL</td>
</tr>
<tr>
<td>44</td>
<td>DOEL–SOLD</td>
<td>DOEL–LOAD</td>
</tr>
<tr>
<td>45</td>
<td>STER–TEETH</td>
<td>STER–TRASH</td>
</tr>
<tr>
<td>46</td>
<td>VER–WEAVE</td>
<td>VER–LOVE</td>
</tr>
<tr>
<td>47</td>
<td>DIEN–TIE</td>
<td>DIEN–FRIEND</td>
</tr>
<tr>
<td>48</td>
<td>ZIEN–SIZE</td>
<td>ZIEN–HIVE</td>
</tr>
<tr>
<td>49</td>
<td>VIES–CAUSE</td>
<td>VIES–GUISE</td>
</tr>
<tr>
<td>50</td>
<td>VLIES–VIEW</td>
<td>VLIES–CLOSE</td>
</tr>
<tr>
<td>51</td>
<td>NIES–SIDE</td>
<td>NIES–KEEN</td>
</tr>
<tr>
<td>52</td>
<td>KIES–PRIDE</td>
<td>KIES–HEIGHT</td>
</tr>
</tbody>
</table>
### Non-rhyming Conditions (R–)

<table>
<thead>
<tr>
<th>Pair No.</th>
<th>Dutch prime – English consistent target</th>
<th>Dutch prime – English inconsistent target</th>
</tr>
</thead>
<tbody>
<tr>
<td>53</td>
<td>MEST–FRAME</td>
<td>MEST–SMOOTH</td>
</tr>
<tr>
<td>54</td>
<td>SPOED–SEAL</td>
<td>SPOED–KNEAD</td>
</tr>
<tr>
<td>55</td>
<td>ZOET–TEACH</td>
<td>ZOET–BOTH</td>
</tr>
<tr>
<td>56</td>
<td>MOED–MEAL</td>
<td>MOED–HEAD</td>
</tr>
<tr>
<td>57</td>
<td>KNOL–FOLK</td>
<td>KNOL–GONE</td>
</tr>
<tr>
<td>58</td>
<td>SCHIM–CHEAP</td>
<td>SCHIM–CHILD</td>
</tr>
<tr>
<td>59</td>
<td>RIOOL–GIRL</td>
<td>RIOOL–ROOT</td>
</tr>
<tr>
<td>60</td>
<td>KOOL–MONK</td>
<td>KOOL–LOSS</td>
</tr>
<tr>
<td>61</td>
<td>BEEK–KEPT</td>
<td>BEEK–BEAT</td>
</tr>
<tr>
<td>62</td>
<td>STREEK–SENT</td>
<td>STREEK–SHARE</td>
</tr>
<tr>
<td>63</td>
<td>SPOOR–PROUD</td>
<td>SPOOR–PORK</td>
</tr>
<tr>
<td>64</td>
<td>BOOR–TORN</td>
<td>BOOR–HOOD</td>
</tr>
<tr>
<td>65</td>
<td>KOOR –WROTE</td>
<td>KOOR –WORTH</td>
</tr>
<tr>
<td>66</td>
<td>GEEST–GRAPE</td>
<td>GEEST–BRUISE</td>
</tr>
<tr>
<td>67</td>
<td>FEEST–STAFF</td>
<td>FEEST–TEASE</td>
</tr>
<tr>
<td>68</td>
<td>LEEST–SEEM</td>
<td>LEEST–LOSE</td>
</tr>
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<td>69</td>
<td>SNOR–WORSE</td>
<td>SNOR–SLOW</td>
</tr>
<tr>
<td>70</td>
<td>BORD–CROWD</td>
<td>BORD–STOOD</td>
</tr>
<tr>
<td>71</td>
<td>KORT–SHORE</td>
<td>KORT–TOUCH</td>
</tr>
<tr>
<td>72</td>
<td>VLOED–SCALE</td>
<td>VLOED–BONE</td>
</tr>
</tbody>
</table>
Table A8. Dutch-English Rhyme Priming Task: Practice Items

<table>
<thead>
<tr>
<th>Pair No.</th>
<th>Rhyming Conditions</th>
<th>Non-rhyming Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dutch prime – English (in)consistent target</td>
<td>Dutch prime – English (in)consistent target</td>
</tr>
<tr>
<td>1</td>
<td>HAAI–BYE</td>
<td>HAAI–RAIN</td>
</tr>
<tr>
<td>2</td>
<td>ROEP–SCOOP</td>
<td>ROEP–SOAR</td>
</tr>
<tr>
<td>3</td>
<td>TEER–YEAR</td>
<td>TEER–TRAY</td>
</tr>
<tr>
<td>4</td>
<td>MEER–NEER</td>
<td>MEER–DEAD</td>
</tr>
<tr>
<td>5</td>
<td>LOEP–DROOP</td>
<td>LOEP–LOUD</td>
</tr>
<tr>
<td>6</td>
<td>PEEN–CRANE</td>
<td>PEEN–WRAP</td>
</tr>
<tr>
<td>7</td>
<td>HOND–FOND</td>
<td>HOND–BARN</td>
</tr>
</tbody>
</table>
Table A9. *Dutch-English Rhyme Judgment: Mean Word Length and Frequency*

<table>
<thead>
<tr>
<th>Stimulus type</th>
<th>Condition</th>
<th>Length*</th>
<th>Frequency^*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dutch prime word</td>
<td>Rhyming/Non-rhyming</td>
<td>4.4</td>
<td>5410.9</td>
</tr>
<tr>
<td>English consistent target word</td>
<td>Rhyming</td>
<td>4.5</td>
<td>94.7</td>
</tr>
<tr>
<td>English inconsistent target word</td>
<td>Rhyming</td>
<td>4.4</td>
<td>97.7</td>
</tr>
<tr>
<td>English consistent target word</td>
<td>Non-rhyming</td>
<td>4.5</td>
<td>89.8</td>
</tr>
<tr>
<td>English inconsistent target word</td>
<td>Non-rhyming</td>
<td>4.6</td>
<td>90.2</td>
</tr>
</tbody>
</table>

*^Mean values based on CELEX for the Dutch words and on Kucera & Francis, 1967 for the English words
### Table A10. Dutch-English Rhyme Judgment: Graphemic Similarity

<table>
<thead>
<tr>
<th>Condition</th>
<th>Graphemic Similarity*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rhyming Dutch prime – English consistent target (R+C+)</td>
<td>271.7</td>
</tr>
<tr>
<td>Rhyming Dutch prime – English inconsistent target (R+C–)</td>
<td>255.4</td>
</tr>
<tr>
<td>Non-rhyming Dutch prime – English consistent target (R–C+)</td>
<td>267</td>
</tr>
<tr>
<td>Non-rhyming Dutch prime – English inconsistent target (R–C–)</td>
<td>259</td>
</tr>
</tbody>
</table>

*Mean graphemic similarity values based on Van Orden, 1987
Participant Questionnaire

Part I

1. Date of birth: ______________________________

2. Year in school (if applicable): ________________________

3. Gender: ______________________________

Part II

Please indicate your preference in the use of hands in the following activities by putting an X in the appropriate column. Where the preference is so strong that you would never try to use the other hand unless absolutely forced to, put an XX. For any activities where you are really indifferent about which hand to use, put an X in both columns.

Some of the activities require both hands. In these cases the part of the task, or object, for which hand preference is wanted is indicated in parentheses. Please try to answer all the questions, and write NA for the activity if you have no experience at all of the object or task.

<table>
<thead>
<tr>
<th></th>
<th>R</th>
<th>L</th>
<th>R</th>
<th>L</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>writing</td>
<td>11</td>
<td>tennis racket</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>drawing</td>
<td>12</td>
<td>golf club (lower hand)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>throwing</td>
<td>13</td>
<td>broom (upper hand)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>scissors</td>
<td>14</td>
<td>rake (upper hand)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>comb</td>
<td>15</td>
<td>striking a match</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>toothbrush</td>
<td>16</td>
<td>opening a box</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>knife</td>
<td>17</td>
<td>dealing cards (card being dealt)</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>spoon</td>
<td>18</td>
<td>threading a needle (whichever is moved)</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>hammer</td>
<td>19</td>
<td>foot you prefer to kick with</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>screwdriver</td>
<td>20</td>
<td>eye you use when you use only one</td>
<td></td>
</tr>
</tbody>
</table>

Part III

1. Do you consider yourself right handed ____ left handed ____ ambidextrous ____

2. Is there anyone in your family (blood relations) who is left-handed?  No _____  Yes _____
   If yes, please list relationship(s) ____________________________________________

3. Did you ever change your handedness?  No _____  Yes _____
   If yes, when & why? _________________________________________________________

4. Is there any activity not listed in Part II for which you consistently use your non-dominant hand?  No _____  Yes _____
Part IV

1. Have you ever been told that you have a reading or learning disability?  No _____ Yes _____

2. Have you ever been diagnosed with a neurological disorder?  No _____ Yes _____

3. Are you currently taking any medications that might affect your brain?  No _____ Yes _____
   *(Note that most over the counter medications do not fit in this category.)*

4. Have you ever had any type of traumatic head injury?  No _____ Yes _____
   *(i.e., that lead to a concussion or loss of consciousness)*

5. Do you have any known visual problems (corrected or uncorrected)?  No _____ Yes _____
   If “Yes”, are they “corrected-to-normal”?  No _____ Yes _____

6. Do you have any known hearing problems (corrected or uncorrected)?  No _____ Yes _____
   If “Yes”, are they “corrected-to-normal”?  No _____ Yes _____

7. What is your native language?  _______________________________________________________

8. What other languages do you know well?  ________________________________________________

Part V (Optional)

Please note that we do not use this section’s data for our analyses. We collect this information because funding agencies like to know the characteristics of the population we include in our studies.

1. Do you consider yourself Hispanic or Latino?  No _____ Yes _____

2. Please indicate your race (check all that apply):
   Asian _____ Black/African-American _____ Native American/Alaska Native _____
   Native Hawaiian/Other Pacific Islander _____ White/Caucasian _____
   Other (Please Specify): __________________

3. Are you disabled?  No _____ Yes _____
Language History Questionnaire (English Monolinguals)

This questionnaire is designed to give us a better understanding of your experience with languages. We ask that you be as accurate and as thorough as possible when answering the following questions.

**PART A**

1. Age (in years):
2. Gender (check one): ☐ Male ☐ Female
3. Education (degree you are pursuing): ☐ BA/BS ☐ MA/MS ☐ PhD/EdD ☐ Other
4. Native Country/Countries (Please check all that apply.)
   - ☐ United States
   - ☐ Other [Please specify: ________________________________]
5. Native Language(s) (Please check all that apply.)
   - ☐ English
   - ☐ Other [Please specify: ________________________________]
6. Language(s) spoken at home. (Please check all that apply.)
   - ☐ English
   - ☐ Spanish
   - ☐ German
   - ☐ Chinese
   - ☐ Other [Please specify: ________________________________]

**Part B**

The next section of the questionnaire deals with your second language learning experience.

7. Have you studied any second language(s)?
   - ☐ No ➔ If NO, please go to Part D (on page 6 of this questionnaire).
   - ☐ Yes ➔ If yes, which language(s)? ____________________________

8. If you studied any second language(s) before college, please check all of the following that apply and indicate the starting age and length of study for any second language(s) learned before college.
   - ☐ Home/Outside of School – Language(s):
     - Starting age? _________ For how long? ______________
   - ☐ Elementary School – Language(s):
     - Starting age? _________ For how long? ______________
   - ☐ Middle School – Language(s):
     - Starting age? _________ For how long? ______________
   - ☐ High School – Language(s):
     - Starting age? _________ For how long? ______________
9. Have you studied any second language(s) in college?

☐ No → **If NO, please go to Question # 13.**
☐ Yes → If yes, which language(s)? ____________________________________________

For how long?

☐ Less than one semester
☐ 1-2 semesters
☐ 3-4 semesters
☐ 5-6 semesters
☐ 7-8 semesters
☐ 8+ semesters

10. Please list the most advanced second language course(s) you have completed in college:

________________________________________________________________________________

11. Are you currently taking at least one second language course in college?

☐ No
☐ Yes → If yes, which course(s)? ________________________________________________

12. Are you: (Please check all that apply and indicate which language each applies to if you have studied more than one second language at college.)

☐ A Spanish, German, etc. 3 student.
☐ Taking a second language for a requirement but interested in being a major or minor.
☐ Taking a second language for a requirement; NOT interested in being a major or minor.
☐ A second language minor.
☐ A second language major.
☐ A second language graduate student.
☐ Other [Please explain: ______________________________________________________]

13. Have you studied and/or lived abroad?

☐ No
☐ Yes

**If YES, where and when did you study, for how long, and what language(s) did you speak?**

<table>
<thead>
<tr>
<th>Country</th>
<th>Approx. dates</th>
<th>Length of Stay</th>
<th>Language</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
14. What do you consider to be your primary second language? (You may check more than one if you feel that you have multiple “primary” second languages.)

☐ English
☐ Spanish
☐ German
☐ Chinese
☐ Other [Please specify: _______________________________________________]

15. What language do you currently think is your dominant language (i.e., the language you are most comfortable using on a daily basis)? (Please check one.)

☐ English
☐ Spanish
☐ German
☐ Chinese
☐ Other [Please specify: _______________________________________________]

16. Do you generally find reading to be challenging or tiresome?

In your native language

☐ Yes ☐ No

In your primary second language (Name language _____________________________)

☐ Yes ☐ No ☐ N/A

In your third language (Name language _________________________________)

☐ Yes ☐ No ☐ N/A

17. Do you usually have a clear understanding of what you have read after reading through the material once?

In your native language

☐ Yes ☐ No

In your primary second language

☐ Yes ☐ No ☐ N/A

In your third language

☐ Yes ☐ No ☐ N/A
18. How would you define your general reading rate?  
(1 = very slow, 3 = average, 5 = very fast)  

In your native language  

1 2 3 4 5  

In your primary second language  

1 2 3 4 5 □ N/A  

In your third language  

1 2 3 4 5 □ N/A  

19. Have you ever been diagnosed with a language or reading disorder in your native or second language?  

In your native language  

□ Yes □ No  

In your primary second language  

□ Yes □ No □ N/A  

In your third language  

□ Yes □ No □ N/A  

If yes, please specify when and what type of disorder  

______________________________________________

______________________________________________
Part C

The next section asks you to rate your skills in your primary second language. If English is your primary second language, then rate yourself on your native language in this section (you will rate your English skills later). If you have more than one “primary” second language, please indicate your skills for each language separately by writing the language next to the number that matches your skill level.

What language(s) are these ratings for? ______________________________________

20. Your reading proficiency in this language. (1=not literate and 7=very literate)
   1  2  3  4  5  6  7

21. Your spelling proficiency in this language. (1=not good and 7=very good)
   1  2  3  4  5  6  7

22. Your writing proficiency in this language. (1=not literate and 7=very literate)
   1  2  3  4  5  6  7

23. Your speaking ability in this language. (1=not fluent and 7=very fluent)
   1  2  3  4  5  6  7

24. Your speech comprehension ability in this language. (1=unable to understand conversation and 7=perfectly able to understand)
   1  2  3  4  5  6  7

25. In my second language classes, I get:
   □ Mostly As
   □ Mostly As and Bs
   □ Mostly Bs
   □ Mostly Bs and Cs
   □ Mostly Cs
Part D

The next section of the questionnaire deals with your English language skills. Please rate yourself on each measure by circling the appropriate number.

These ratings are for ENGLISH.

26. Your English reading proficiency. (1=not literate and 7=very literate)
   1  2  3  4  5  6  7

27. Your English spelling proficiency. (1=not good and 7=very good)
   1  2  3  4  5  6  7

28. Your English writing proficiency. (1=not literate and 7=very literate)
   1  2  3  4  5  6  7

29. Your English speaking ability. (1=not fluent and 7=very fluent)
   1  2  3  4  5  6  7

30. Your English speech comprehension ability. (1=unable to understand conversation and 7=perfectly able to understand)
   1  2  3  4  5  6  7

31. Do you have any additional comments to make? Please include any additional language experience that you have not included in other portions of this questionnaire.

Thank you for your participation!
L2 Language History Questionnaire (Spanish-English Bilinguals)

This questionnaire is designed to give us a better understanding of your experience with languages. We ask that you be as accurate and as thorough as possible when answering the following questions.

PART A

1. Age (in years):

2. Gender (check one): ☐ Male ☐ Female

3. Education (degree you are currently pursuing): ☐ BA/BS ☐ MA/MS ☐ PhD/EdD ☐ Other

4(a). Country of origin:

4(b). Country of Residence:

5. If you have lived or travelled in other countries for more than three consecutive months, please indicate the name(s) of the country or countries, your length of stay, and the language(s) you learned or tried to learn. Also, if you have spent significant time abroad in the same place, but on different occasions, please list each occasion separately.

<table>
<thead>
<tr>
<th>Country</th>
<th>Length of stay (in years, months)</th>
<th>Language(s) learned</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tbody>
</table>
6. What is your native language? (If you grew up with more than one language, please specify)

7. Do you speak a second language?
   - ☐ YES my second language is ___________________________.
   - ☐ NO (If you answered NO, you do not need to continue filling out this form)

8. Please list all the other languages that you know in the order of proficiency. Please rate your reading, writing, speaking and listening proficiency in each language according to the following scale (write down the number in the table):

<table>
<thead>
<tr>
<th>Language</th>
<th>Reading; Writing</th>
<th>Speaking; Listening</th>
<th>Age of acquisition</th>
<th>Context of acquisition (check all that apply)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>☐ home ☐ school ☐ abroad</td>
</tr>
<tr>
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<td></td>
<td></td>
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<td>☐ home ☐ school ☐ abroad</td>
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<td></td>
<td></td>
<td></td>
<td>☐ home ☐ school ☐ abroad</td>
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<td>☐ home ☐ school ☐ abroad</td>
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<td>☐ home ☐ school ☐ abroad</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>☐ home ☐ school ☐ abroad</td>
</tr>
</tbody>
</table>

9. Which language do you consider to be your dominant language (i.e., the language you are most comfortable using on a daily basis)?

10. Please specify the age at which you started to learn your primary second language in the following situations (write age next to any situation that applies).
   - ☐ At home at the age of _____________________
   - ☐ In school at the age of _____________________
   - ☐ After arriving in the second language speaking country at the age of _____________________
11. How did you learn your primary second language up to this point? (check all that apply)

☐ Mainly ☐ Mostly ☐ Occasionally through formal classroom instruction.

☐ Mainly ☐ Mostly ☐ Occasionally through interacting with people.

A mixture of both, but ☐ More classroom ☐ More interaction ☐ Equally both.

12. List your native and primary second language in the order of most proficient to least proficient. Rate your ability on the following aspects in each language. Please rate according to the following scale (write down the number in the table):

<table>
<thead>
<tr>
<th>Very poor</th>
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<th>Very good</th>
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<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Language</th>
<th>Reading proficiency</th>
<th>Writing proficiency</th>
<th>Speaking fluency</th>
<th>Listening ability</th>
</tr>
</thead>
<tbody>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
</tbody>
</table>

13. Provide the age at which you were first exposed to your native and primary second language in terms of speaking, reading, and writing, and the number of years you have spent on learning each language.

<table>
<thead>
<tr>
<th>Language</th>
<th>Age first exposed to the language</th>
<th>Number of years learning</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Speaking</td>
<td>Reading</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

14. Please rate the strength of your foreign accent in your native and primary second language according to the following scale (write down the number in the table):

<table>
<thead>
<tr>
<th>No Accent</th>
<th>Very Weak</th>
<th>Weak</th>
<th>Intermediate</th>
<th>Strong</th>
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</thead>
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</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Language</th>
<th>Accent (circle one)</th>
<th>Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td></td>
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<td>N</td>
</tr>
</tbody>
</table>
PART B

15. Estimate, in terms of percentages, how often you use your native and primary second language per day (in all daily activities combined). Draw a line dividing up the following line and label each side with the name of the language to which the percentage belongs. (For example, if you spend 50% of your time using each language, you would draw a vertical line at 50% and label each side for one of your languages.)

16. Estimate how often you are engaged in the following activities with your native and second languages.

<table>
<thead>
<tr>
<th>Activities</th>
<th>Native Language</th>
<th>Primary Second Language</th>
</tr>
</thead>
<tbody>
<tr>
<td>Listen to Radio/ Watching TV:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reading for fun:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reading for work:</td>
<td></td>
<td></td>
</tr>
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<td>Reading on the Internet:</td>
<td></td>
<td></td>
</tr>
<tr>
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<td></td>
</tr>
<tr>
<td>Writing articles/papers:</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

17. Do you generally find reading to be challenging or tiresome?

   In your native language   In your primary second language
   □ Yes       □ No       □ Yes       □ No

18. Do you usually have a clear understanding of what you have read after reading through the material once?

   In your native language   In your primary second language
   □ Yes       □ No       □ Yes       □ No
19. How would you define your general reading rate?
   (1 = very slow, 3 = average, 5 = very fast)

   In your native language  In your primary second language
   1  2  3  4  5          1  2  3  4  5

20. Have you ever been diagnosed with a language or reading disorder in your native or second language?

   In your native language  In your primary second language
   ☐ Yes  ☐ No          ☐ Yes  ☐ No

If yes, please specify when and what type of disorder

______________________________________________________________________________

21. Estimate how often you speak your native and primary second language with the following people.

   Several hours each day  Several hours a week, but not necessarily each day
   A few times a month, but not necessarily each week  Rarely, if ever

   1                  2                 3                  4

   Native Language      Primary Second Language
   Spouse/family members: ____________  ____________
   Friends:              ____________  ____________
   Classmates:           ____________  ____________
   Co-workers:           ____________  ____________

22. Write down the name of the language(s) in which you received the majority of instruction in school, for each schooling level:

   Primary/Elementary School: __________________________
   Secondary/Middle School: __________________________
   High School:                                      __________________________
   College/University: __________________________
23. In which language do you usually:

   Count, add, multiply, and do simple arithmetic? ________________________

   Dream? ________________________

   Express anger or affection? ________________________

24. When you are speaking, do you ever mix words or sentences from the two or more languages you know? (If no, skip to question 26).

25. List the languages that you mix and rate the frequency of mixing in normal conversation with the following people according to the following scale (write down the number in the table):

<table>
<thead>
<tr>
<th>Rarely</th>
<th>Occasionally</th>
<th>Sometimes</th>
<th>Frequently</th>
<th>Very Frequently</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Relationship</th>
<th>Languages mixed</th>
<th>Frequency of mixing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spouse/family members</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Friends</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Co-workers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Classmates</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

26. In which of your two main languages do you feel you usually do better? Write the name of the language under each condition.

   Reading ________________________

   Writing ________________________

   Speaking ________________________

   Understanding ________________________
27. Between your native and primary second language, which one do you typically use in these situations?

At home

At work

At a party

In general

28. If there is anything else that you feel is interesting or important about your language background or language use, please comment below.

Thank you for your participation!
L2 Language History Questionnaire (Chinese-English Bilinguals)

This questionnaire is designed to give us a better understanding of your experience with languages. We ask that you be as accurate and as thorough as possible when answering the following questions.

**PART A**

1. Age (in years):

2. Gender (check one): □ Male  □ Female

3. Education (degree you are currently pursuing): □ BA/BS □ MA/MS □ PhD/EdD □ Other

4(a). Country of origin:

4(b). Country of Residence:

5. If you have lived or travelled in other countries for more than three consecutive months, please indicate the name(s) of the country or countries, your length of stay, and the language(s) you learned or tried to learn. Also, if you have spent significant time abroad in the same place, but on different occasions, please list each occasion separately.

<table>
<thead>
<tr>
<th>Country</th>
<th>Length of stay (in years, months)</th>
<th>Language(s) learned</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
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<td></td>
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<td></td>
</tr>
</tbody>
</table>
6. What is your native language? (If you grew up with more than one language, please specify)

7. Are you a native speaker of ☐ Mandarin Chinese or ☐ Cantonese Chinese?

8. Please rate your knowledge and frequency of use of traditional and simplified Chinese characters, as well as of Pinyin. Please rate according to the following scale (write down the number in the table):

<table>
<thead>
<tr>
<th>Writing system</th>
<th>Age of initial exposure</th>
<th>Proficiency</th>
<th>Frequency of use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional Chinese characters</td>
<td></td>
<td></td>
<td>☐ daily ☐ weekly ☐ monthly</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>☐ a few times a year ☐ rarely</td>
</tr>
<tr>
<td>Simplified Chinese characters</td>
<td></td>
<td></td>
<td>☐ daily ☐ weekly ☐ monthly</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>☐ a few times a year ☐ rarely</td>
</tr>
<tr>
<td>Pinyin</td>
<td></td>
<td></td>
<td>☐ daily ☐ weekly ☐ monthly</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>☐ a few times a year ☐ rarely</td>
</tr>
</tbody>
</table>

9. Do you speak a second language?

☐ YES my second language is ________________________________.
☐ NO (If you answered NO, you do not need to continue filling out this form)

10. Please list all the other languages that you know in the order of proficiency. Please rate your reading, writing, speaking and listening proficiency in each language according to the following scale (write down the number in the table):

<table>
<thead>
<tr>
<th>Language</th>
<th>Reading; Writing</th>
<th>Speaking; Listening</th>
<th>Age of acquisition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>(check all that apply)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>☐ home ☐ school ☐ abroad</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>☐ home ☐ school ☐ abroad</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>☐ home ☐ school ☐ abroad</td>
</tr>
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<td>☐ home ☐ school ☐ abroad</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>☐ home ☐ school ☐ abroad</td>
</tr>
</tbody>
</table>
11. Which language do you consider to be your dominant language (i.e., the language you are most comfortable using on a daily basis)?

12. Please specify the age at which you started to learn your primary second language in the following situations (write age next to any situation that applies).

   - At home at the age of ______________
   - In school at the age of ______________
   - After arriving in the second language speaking country at the age of ______________

13. How did you learn your primary second language up to this point? (check all that apply)

   - Mainly
   - Mostly
   - Occasionally through formal classroom instruction.
   - Mainly
   - Mostly
   - Occasionally through interacting with people.
   - A mixture of both, but
   - More classroom
   - More interaction
   - Equally both.

14. List your native and primary second language in the order of most proficient to least proficient. Rate your ability on the following aspects in each language. Please rate according to the following scale (write down the number in the table):

<table>
<thead>
<tr>
<th>Very poor</th>
<th>Poor</th>
<th>Fair</th>
<th>Functional</th>
<th>Good</th>
<th>Very good</th>
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15. Provide the age at which you were first exposed to your native and primary second language in terms of speaking, reading, and writing, and the number of years you have spent on learning each language.

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<td></td>
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16. Please rate the strength of your foreign accent in your native and primary second language according to the following scale (write down the number in the table):

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<td>Y   N</td>
<td></td>
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PART B

17. Estimate, in terms of percentages, how often you use your native and primary second language per day (in all daily activities combined). Draw a line dividing up the following line and label each side with the name of the language to which the percentage belongs. (For example, if you spend 50% of your time using each language, you would draw a vertical line at 50% and label each side for one of your languages.)

| 0% | 10% | 20% | 30% | 40% | 50% | 60% | 70% | 80% | 90% | 100% |

18. Estimate how often you are engaged in the following activities with your native and second languages.

<table>
<thead>
<tr>
<th>Several hours each day</th>
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<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

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</thead>
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19. Do you generally find reading to be challenging or tiresome?

In your native language

☐ Yes  ☐ No

In your primary second language

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20. Do you usually have a clear understanding of what you have read after reading through the material once?

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21. How would you define your general reading rate?

(1 = very slow, 3 = average, 5 = very fast)

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1  2  3  4  5

In your primary second language

1  2  3  4  5

22. Have you ever been diagnosed with a language or reading disorder in your native or second language?

In your native language

☐ Yes  ☐ No

In your primary second language

☐ Yes  ☐ No

If yes, please specify when and what type of disorder

________________________________________________________________________

23. Estimate how often you speak your native and primary second language with the following people.

Several hours each day  Several hours a week, but not necessarily each day  A few times a month, but not necessarily each week  Rarely, if ever

1  2  3  4

Native Language  Primary Second Language

Spouse/family members:  

Friends:  

Classmates:  

Co-workers:  

24. Write down the name of the language(s) in which you received the majority of instruction in school, for each schooling level:

   Primary/Elementary School: ______________________________

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25. In which language do you usually:

   Count, add, multiply, and do simple arithmetic? ____________________________

   Dream? ____________________________

   Express anger or affection? ____________________________

26. When you are speaking, do you ever mix words or sentences from the two or more languages you know? (If no, skip to question 26).

27. List the languages that you mix and rate the frequency of mixing in normal conversation with the following people according to the following scale (write down the number in the table):

   Rarely 1   Occasionally 2   Sometimes 3   Frequently 4   Very Frequently 5

<table>
<thead>
<tr>
<th>Relationship</th>
<th>Languages mixed</th>
<th>Frequency of mixing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spouse/family members</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Friends</td>
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<tr>
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28. In which of your two main languages do you feel you usually do better? Write the name of the language under each condition.

   Reading  ______________________
   Writing   ______________________
   Speaking  ______________________
   Understanding  ______________________

29. Between your native and primary second language, which one do you typically use in these situations?

   At home  ______________
   At work   ______________
   At a party  ______________
   In general  ______________

30. If there is anything else that you feel is interesting or important about your language background or language use, please comment below.

   ____________________________________________

   Thank you for your participation!
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processes mediating rhyme judgments: Phonological and orthographic interactions.

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2009-2012 Research Assistant and Lab Manager, The Brain, Language, and Literacy Laboratory, Department of Communication Sciences and Disorders, The Pennsylvania State University
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