ALPHABETIC PROCESSING IN ENGLISH AND SPANISH

By

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DEDICATION

I wish to dedicate this dissertation to my parents. To my father, whom I am named after, who provided the example I needed to become a thinker. And to my mother, Janice, who has always believed in me.

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ABSTRACT

This dissertation used letter detection and masked priming to address four questions: Are graphemes or letters more fundamental in low-level reading processes? How does alphabetic-processing knowledge manifest in different languages? Do bilinguals transfer such knowledge across languages? And do young children also show such effects?

Some researchers have recently revived an old hypothesis in which graphemes, not letters, are the fundamental, perceptual reading unit. This can be tested by looking at congruency effects in a letter-detection task with masked priming. Six groups participated: Spanish and English monolingual adults; Spanish- and English-dominant bilingual adults; Spanish-dominant bilingual children; and English monolingual children. The experiments with adult monolinguals tested the letter- against the grapheme-as-percept hypothesis. The experiments with developing bilinguals examined whether they would transfer alphabetic-processing knowledge from L1 to L2. And the experiments with English monolingual children probed how early congruency effects with masked primes might occur.

Participants responded YES or NO depending on the presence of letters in targets. Both congruent and incongruent masked primes preceded the targets. Among the congruent primes, some contained double vowels, and others single vowels. Assuming letters are fundamental, single- and double-vowel primes in both languages should facilitate and inhibit reactions equally. Assuming graphemes are fundamental, single-

vowel primes in English, but not Spanish, should facilitate and inhibit more because double vowels are digraphs in English, and should therefore conceal the identity of their component letters. Bilinguals should show L1-like effects in L2 if they transfer alphabet-specific processing knowledge. Young children should simply show congruency effects if they are able to process letter information automatically.

The results with Spanish and English monolinguals suggested that graphemes do exert an effect on the task, but only after letters are perceived. This has major implications for models of proficient reading. The results also suggest that Spanish readers do not construct graphemes from letters, but rather syllables and abstract syllable structure. Bilinguals showed evidence of L1-L2 transfer at low levels of L2 proficiency. This has implications for transitional bilingual education programs. And young children showed congruency effects, which provides another link in establishing the connection between literacy development and proficient reading.

CHAPTER 1 INTRODUCTION

1.1 Basic issues

This dissertation concerns how letters are processed in different languages, when this letter-processing knowledge emerges, and whether and how processing in one alphabet is applied to another alphabet in second-language reading. Although letter detection is the fundamental task in my experiments, my treatment of letter processing goes beyond the letter level. It examines groups of letters and how they combine to represent various levels of linguistic knowledge.

The transfer of processing knowledge is a type of *linguistic transfer*. Linguistic transfer is the application of knowledge and/or skills from one language to another, usually from one's first language to one's second language. In this case, the issue is transfer of language-processing knowledge, not of language knowledge, per se (which is the traditional focus of transfer studies).

In all, I ask four questions in this dissertation: (a) What is the basic unit of visual word recognition in alphabetic orthographies? (b) Do readers of different alphabetic orthographies process the same letter groups differently across languages? (c) If so, does this knowledge transfer across languages? And (d) when does this automatic alphabetic processing knowledge begin to emerge?

The first question addresses the recent revival of a hypothesis first advanced in the 1960s that was abandoned by the 1970s. This hypothesis held that it was not letters that readers of alphabetic orthographies initially perceived visually, but rather *graphemes*.

For alphabetic orthographies, the grapheme is usually defined as any single letter or string of letters that represents one phoneme (Venetzky, 1970). They are derived from grapheme-phoneme correspondences, which are the associations between letters or multiple letters and their phonemic representations. For example, the grapheme S in English usually represents the phoneme /s/, as in SMART. But the letter S also combines with the letter H to form the grapheme SH, which represents the phoneme /ʃ/, as in SHOE. This hypothesis suggested that the phoneme ultimately governs how readers process letters. On this view, English readers would perceive S and SH as independent reading units.[1]

A few researchers have revived this hypothesis (e.g., Plaut et al., 1996; Rey et al., 1998; Rey, Ziegler, & Jacobs, 2000). In letter detection experiments, Rey et al. (2000) found that English and French participants took longer to identify vowel letters in words when the vowel letters were part of multi-letter vowel graphemes (e.g., the E in the multi-letter grapheme EA in the word BR<u>EA</u>D) than when the vowel letters were by themselves (e.g., the E in SP<u>E</u>CK). They argued that since the task did not involve identifying or naming words in any way, this delay in letter identification could only be explained as having occurred on basic perceptual units. For Rey et al., only a model that used graphemes as basic percepts could explain the results.

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[1] Interestingly, the phoneme /i/ in the English word ENCYCLOP<u>E</u>DIA can be spelled alternatively with the ligature Æ (ENCYCLOP<u>Æ</u>DIA), as it can also in the word DEMON (D<u>Æ</u>MON). This is a useful analogy in understanding the proposal here.

My experiments address this question by building on these recent studies to test whether graphemes can be perceived independently of letters. Following Rey et al. (2000), my focus will be the vowel digraph. As suggested above, a vowel digraph is any pair of letters that correspond to one vocalic phoneme in a particular language. In English for instance, EA in the word FEAST is a vowel digraph corresponding to the phoneme /i/.

The difference between this dissertation and Rey et al. (2000) lies mainly with how participants perceive the experimental stimuli. In Rey et al.'s experiments, the conditions (vowels by themselves vs. vowels in digraphs) were available for participants to see consciously in the targets, even though they were not told about them. In my experiments, the conditions were not consciously available for participants. This is important since the revived claim is that graphemes are perceived first, before any conscious operation can be executed. In order to rule out the possibility that conscious processes were responsible for the effects that these researchers found, the experiments must tap automatic processing. My dissertation takes a step in this direction.

The experimental method I used was a type of general priming known as masked priming. General priming experiments involve presenting one stimulus before another to see what effect the former has on the latter. The first stimulus is referred to as the *prime*, and the second as the *target*. Participants are told to ignore the primes and respond only to targets. But in masked priming experiments, primes are presented very quickly (usually between 30-60 ms) with masks before and after them (in the standard approach). A *mask* is a visual pattern that occupies the same space on the computer screen, yet is different in visual form from that of the prime. This sequence of stimuli makes it difficult to perceive the prime. In fact, most participants do not report having seen anything, let alone a prime, at prime durations at 50 ms or below (Forster, Mohan, & Hector, 2003). When participants are not aware of the prime, effects can be attributed to automatic, subconscious processes.

The second question addressed by this dissertation is whether readers perceive visually identical letter strings in the same way across languages. Different (and often linguistically unrelated) languages may share an identical, or nearly identical, set of letters. For instance, English, French, Spanish, Italian, German, Vietnamese, Tagalog, Maltese Arabic, and Turkish all use roman letters. But any letter or letter combination shared by these languages is likely to represent linguistic units in different ways depending on the language. For instance, the SCH in German always represents one phoneme (e.g., SCHULE /ʃulə/), whereas in English it usually represents two (e.g., SCHOOL /skul/). This dissertation investigates how vowel letters are processed when embedded in these multi-letter units.

I will investigate this problem by testing in two languages that share letters of the roman alphabet: English and Spanish.[2, 3] The fact that graphemes represent phonemes

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[2] Although English and Spanish share all letters, not all are used to the same extent. The two most extreme examples are the letters K and W. These letters are used in Spanish for foreign words only, making them quite rare. But they are fairly common letters in English. If one excludes diacritics (see footnote below), then all Spanish letters are used fairly often in English.

differently in the two languages provides grounds to think that letters are processed differently in each. The participants for this question and the question of whether graphemes are percepts were English and Spanish monolingual adults. These experiments are covered in Chapter 4.

The third question is how bilingual readers apply processing knowledge derived from their first language to read in their second language. A few researchers (e.g., Akamatsu, 1999; Geva, Wade-Woolley, & Shany, 1993; Koda, 1989) have looked at this issue extensively from a perspective of dissimilarity. That is, most of their research emphasizes that bilingual readers will read their second language like their first when the two scripts are dissimilar in some significant way. For instance, Chinese orthography represents morphemes that cannot be decomposed into smaller linguistic units;[4] so when a native Chinese reader learns to read English, she may be inclined to read English words as un-analyzable wholes.

But this dissertation approaches the subject from a perspective of similarity. As noted above, different languages can share similar or identical writing symbols. When this is the case, as it is in English and Spanish, second-language readers might be even

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[3] For the purposes of this dissertation, I am not considering Spanish letters with diacritics (e.g., Á, Ñ, Ü) to be distinct letters. Interestingly, Spanish includes Ñ and most of the digraphs of the language (i.e., CH, LL, RR,) as separate members of the recited alphabet (i.e., separate from N, C, H, L, and R). English does not include digraphs in its recited alphabet. This may say something about how we classify digraphs in a conscious sense, but that is not the focus of this dissertation.

[4] It should be noted that even though all Chinese characters represent morphemes, a particular character's function can be phonological in many two-character compounds.

more inclined to read in their second language as if it were their first. This is because it might be difficult to overcome any connections that may have been established in one's first language between particular orthographic representations (letters) and their phonological referents. After all, there are typically more visual cues to suggest to such readers that the systems are the same than there are visual cues to suggest them that the two systems are different. So far just a few studies have been carried out with this in mind (e.g., Gesi Blanchard, 1998; Green & Meara, 1987). This dissertation addresses this gap by giving the letter-detection task to bilingual adults in both English and Spanish, and to bilingual children in English. These experiments are covered in Chapters 5 and 6.

The fourth question is how early automatic alphabetic processing knowledge emerges. Most children begin some sort of reading instruction by the first grade. But the average child in the English-speaking world does not become a very skilled reader until about the fifth grade (Jackson & Coltheart, 2001). Adult-like reading behavior may occur earlier in shallower orthographies since children reading such languages develop the component sub-skills of reading earlier (Frith, Wimmer, & Landerl, 1998; Seymour, Aro, & Erskine, 2003; Wimmer, Landerl, & Frith, 1999). But at some point in reading development, readers must learn to process letters or graphemes subconsciously. This dissertation looks at whether third, fourth, and fifth graders process letters and/or graphemes subconsciously. These experiments are covered in Chapter 6.

To review, my research addresses multi-letter grapheme processing in English and Spanish, whose alphabetic orthographies share all letters but differ a good deal in how those letters map to phonological units. I used letter detection with masked priming to do so. My participants included the following six groups: (a) English monolingual adults; (b) Spanish monolingual adults; (c) English-dominant bilingual adults learning Spanish; (d) Spanish-dominant bilingual adults learning English; (e) monolingual English children; and (f) Spanish-dominant bilingual children learning English. The results with the monolingual adults will help elucidate whether graphemes or letters are the basic units of visual word recognition, and how this plays out in different alphabetic orthographies that share roman letters. The results with the two groups of bilingual adults and the one group of bilingual children will tell us how bilingual readers use knowledge from their first language to read in their second. And finally, the results with the monolingual English children will help us determine how early readers of alphabetic orthographies begin to process letters automatically.

1.2 Implications of this dissertation

My research should inform several domains, including models of reading, bilingual education, and second language acquisition. First, this dissertation will help determine whether multi-letter grapheme-phoneme correspondences become basic perceptual units among proficient readers. For alphabetic orthographies, all current models of lexical access and letter-string naming incorporate some role for grapheme-phoneme correspondences. But whether readers perceive graphemes alongside or in lieu of letters is an open question.

Second, my research will inform educational theory and practice, albeit less directly. With respect to reading, we still do not know how processing in one language transfers to another. Literacy in a first language should facilitate literacy in a second in many ways (Bialystok, Luk, & Kwan, 2005; Cummins, 1984; Durgunoğlu, 1998). Yet we know little about alphabetic transfer, or what kind of effects it might have on the developing reader. My research will add to educational theory by helping determine whether alphabetic transfer occurs in the first place. Later research can then address its educational impact.

Finally, this dissertation will inform second language acquisition. Most research on reading has been carried out with respect to first language. Most studies concentrate on literacy development and adult reading. Studies that focus on literacy development or proficient reading among bilinguals are fewer, though growing in number. This growth makes sense since a very large proportion of people worldwide speak more than one language (Crystal, 1997; Grosjean, 1982). Thus, the findings from my research will add to an often overlooked, but vital, area of second language acquisition.

This dissertation also forms the foundation for a long-term research agenda. Alphabetic orthographies differ in many interesting ways. Some writing systems are easy both to read and write (e.g., Serbo-Croatian: Frost, Katz, & Bentin, 1987). Some are easy to read, but more difficult to write (e.g., Greek: Harris & Giannouli, 1999; French: Sprenger-Charolles, Siegel, & Bonnet, 1998). Some are easier to write than to read (e.g., unpointed Hebrew; Share & Levin, 1999; unpointed Arabic: Taouk & Coltheart, 2004).

Still others are difficult both to read and write (e.g., English: Venetzky, 1970).[5] Recent studies in cognitive science have begun to compare how orthographic processing knowledge is instantiated in proficient monolingual readers across languages (e.g., Frost, Katz, & Bentin, 1987; Goswami et al., 2003; Katz & Frost, 1992; Lukatela & Turvey, 1995; Ziegler et al., 2001), but fewer have investigated what happens among bilinguals. This dissertation seeks to discover not only how monolinguals and bilinguals process letters and graphemes, but also how bilinguals might transfer processing knowledge acquired in their first language to their second language. It seems appropriate at this time to address how reading might occur in the majority of the world's population.

1.3 Preliminaries

Before detailing my experiments in Chapters 4-6, I will describe some of the relevant background literature in the next two chapters. As noted above, a few researchers (e.g., Plaut et al., 1996; Rey, Ziegler, & Jacobs, 2000) have begun to claim that graphemes, instead of letters, are the basic perceptual reading units in alphabetic orthographies. But they do this mostly on the basis of a few experiments (Rey et al., 1998; Rey, Ziegler, & Jacobs, 2000) and a particular computational model (Plaut et al., 1996). The theoretical backing is still under development.

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[5] The volume by Harris and Hatano (1999) includes many papers that discuss the relative difficulties of learning to read and write in different alphabets. Also see Caravolas (2004) and Ziegler and Goswami (2005).

Therefore, in Chapter 2, after outlining some of the basic orthographic differences between English and Spanish in terms of depth, I attempt to provide some justification for a model using graphemes as percepts by reviewing different influential models of literacy development. I first review each model arranged in order from the least likely to result in readers eventually using graphemes as percepts, to the most likely. I then compare the first model with each of the others. I end the chapter by reviewing a few important studies concerning graphemes and how they might be basic perceptual reading units.

Chapter 3 then reviews elements more directly relevant to my experiments. These elements include the following: (a) the masked priming paradigm; (b) the materials and design of the experiments; (c) the participant groups; and (d) some general predictions.

CHAPTER 2 THEORETICAL AND EMPIRICAL FOUNDATIONS

This chapter highlights the difference between deep and shallow orthographies, and how current models of reading describe their processing. The discussion begins with descriptions of the English and Spanish orthographies. English is a deep alphabetic orthography, and Spanish is a shallow one. Other shallow orthographies include Serbo-Croatian, Italian, Greek, and German. Other deep orthographies include French and unpointed Hebrew and Arabic. I focus on double-vowel constructions. Not only do double vowels happen to be good examples of the differences between the two orthographies, they are also the experimental locus of this dissertation. I then introduce and compare four models of alphabetic literacy development. The purpose of the comparison is to highlight some recent theorizing about how letters and graphemes are processed. The chapter ends with some recent empirical findings that further motivate my experiments.

2.1 The relative complexity of English orthography

To the proficient reader of English, basic grapheme-phoneme correspondences (GPCs) are obvious. For instance, the word SILK has four letters which correspond to the four sounds(i.e., phonemes) in /sɪlk/.[6] This makes each letter its own grapheme. By using knowledge of GPCs, a reader can determine the pronunciation of written words she

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[6] Unless he has a background in linguistics, the literate layperson will most likely think that letters represent sounds. But strictly speaking, there are no alphabetic writing systems that do this. Letters in alphabets represent phonemes.

has not seen before with a reasonable degree of precision. This process is known as *decoding*. The reader can also determine that the five letters in the written word STICK (four graphemes in this case) correspond to the four phonemes /stɪk/. These basic relations are fairly consistent, and will be reliable guides to identifying new words most of the time (Hanna, Hodges, & Hanna, 1971).

But GPCs in English are not entirely reliable. For instance, there are many exception words that violate the GPCs in some way. The words HAVE, GREAT, and EPITOME are examples of such words (pronounced incorrectly through the use of GPCs as /heʲv/, /grit/, and /ɛpɪtom/, respectively). This inconsistency is magnified in the case of generating spellings for words, since alternative spellings for particular phonemes are higher in number than alternative pronunciations for particular spellings (Jackson & Coltheart, 2001). For example, the phoneme /u/ can be written with at least 15 different spellings. Examples are U (ADDUCE), UE (TUESDAY, PSEUDONYM), UI (SUIT), O (ADO, MOVE), OE (SHOE), OO (BLOOM), OU (GROUP), EW (CHEW), EU (NEUTER), WO (TWO), IEU (LIEU), OUS (RENDEZVOUS), OUP (COUP), OUGH (THROUGH), and the split digraph U_E (RUDE).[7] In contrast, the letter pair OO refers to only four phonemes: /ʊ/ (LOOK), /u/ (SOON), /o/ (DOOR), and /ʌ/ (BLOOD).

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[7] Split digraphs come in the form of a vowel followed by a consonant, and then a so-called "silent E." An example is in the word CRUDE, where the final E tells the reader that the central vowel U is pronounced like /u/ (as opposed to /ʌ/, which would lead to the pronunciation of the word CRUD).

Some English words contain identical letter sequences that are pronounced differently because those letter sequences correspond to a particular morpheme. This sometimes forces the reader to ignore the GPCs and appeal to some other mechanism for word recognition (e.g., letter strings corresponding to morphemes, or perhaps words). A famous example in English is -SIGN-. This morpheme is pronounced differently, for example, in the words ASSIGN /əsɑʲn/, DESIGN /dɛzaʲn/, SIGNAL /sɪgnəl/, DESIGNATE /dɛzɪgneʲt/, and ENSIGN /ɛnsɪn/. This phonological inconsistency can impede literacy development, though the morphological consistency may eventually help the reader in certain ways by showing her that there are morphological and, thus, semantic relations among some words even when they sound very different.[8]

Another aspect of the depth of the English orthography is highlighted by orthographic rimes. A phonological rime is a sub-syllabic unit consisting of the first vowel in a syllable and any consonants that follow. An orthographic rime is simply the written equivalent. Figure 1 below depicts this hierarchical view of the syllable along with the example words STARK, ARK, STAMP, and AMP. [9,10] The grapheme A represents different phonemes in STARK and STAMP (/ɑ/ and /æ/, respectively). This will cause some confusion for the beginning reader, who might decode STAMP not as the correct form

[8] This is the morphological transparency that Chomsky and Halle (1968) noted in their discussions of English phonology. They suggested this sort of orthographic representation may be ideal for English.
[9] The onset is a consonant or consonant cluster that precedes the rime in many syllables. The coda is a consonant or consonant cluster than follows the nucleus in many syllables. The nucleus and, by extension, the rime are required elements in all syllables.
[10] For a review of other, less influential theories of syllable structure, see Blevins (1995).

/stæmp/, but as /stɑmp/ (sounding like STOMP). This phonological inconsistency may impede literacy to some degree.

Of course, as readers become more proficient in English, they will see that A is almost always pronounced as /ɑ/ in the orthographic rime -ARK (e.g., LARK, SHARK, BARK, MARK) and as /æ/ in the orthographic rime -AMP (e.g., LAMP, RAMP, CAMP).[11] In fact, associations between orthographic rimes and phonology can also be used to decode novel words. Some researchers suggest that orthographic rimes play an important role in the recognition of English words (e.g., Treiman & Chafetz, 1987; Ziegler & Goswami, 2005). This issue is not central to this dissertation, per se, but the discussion of it in the literature has implied certain things about graphemes, which are central to the dissertation. So later in this chapter, I return to the issue of orthographic rimes.

[11] Out of the 34 words with the letter sequence -ARK, the only exception to the /ɑrk/ pronunciation is in the low-frequency word BULWARK /bʌlwərk/. Out of the 48 words with the letter sequence -AMP, the only exception to the /æmp/ pronunciation is in the word SWAMP /swamp/.

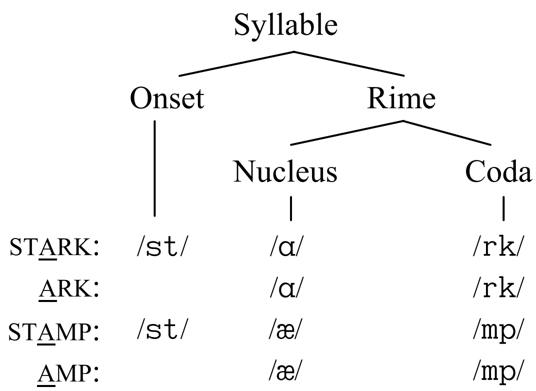

FIGURE 1. Different pronunciations of the letter A in the words STARK, ARK, STAMP, and AMP according to syllabic rime context.

The preceding discussion shows that English orthography is relatively opaque, or deep. This depth is frequently associated with literacy problems in the English-speaking world. But there may be a sort of distributed transparency in English, where lack of consistency at one level of analysis (i.e., GPCs) can be compensated with consistency at another (e.g., morphemes, orthographic rimes). I return to this issue when reviewing different models of literacy development. It is particularly relevant for Ziegler and Goswami’s (2005) psycholinguistic grain-size theory.

But another aspect of orthographic complexity in English has to do with the sheer number of multi-letter graphemes. With varying levels of consistency, English has a large number of multi-letter graphemes to represent all its phonemes (Caravolas, 2004; Crystal, 1997; Rayner et al., 2001). Coulmas (2003, p. 184) reports that on one account (Nyikos, 1988), just over 1,100 graphemes represent the approximately 40 phonemes of English. And this is most apparent in the vowel system (Coulmas, 2003).

I focus on double-vowel graphemes in this dissertation, so I will focus on these to exemplify the topic. Excluding diphthongs, there are between 11-12 monophthongal spoken vowels in English depending on the dialect (Clark & Yallop, 1995; Crystal, 1997). But there are only 5 vowel letters. So in addition to single vowel letters performing double and triple duty in representing different phonemes (e.g., the O in COMB, SON, and BLONDE), some vowel phonemes are represented with *digraphs* (Caravolas, 2004). A digraph is a two-letter grapheme representing one phoneme. In fact, double vowels in English are usually digraphs, but there are exceptions. For instance, the EA is pronounced as /iæ/ in the words SEATTLE, MEANDER, and BEATITUDE. However, out of 265 three-to-six letter words with EA as a letter sequence found in the online MRC Psycholinguistic Database (Wilson, 1987), only 10 words could be unambiguously identified as having EA represent /iæ/.

This aspect of English orthography means that a vowel letter may represent the vowel phoneme either completely (e.g., the E in FRESH), or only partially (e.g., the E in FIELD). Finally, it is worth recalling that the vowel digraphs in English can have one-to-many relations with phonemes (e.g., B<u>EA</u>N /bin/, H<u>EA</u>LTH /hɛlθ/, and GR<u>EA</u>T /greʲt/ for the EA digraph) and that vowel phonemes can have one-to-many relations with digraphs (e.g., /i/ in S<u>EA</u>M, F<u>EE</u>D, Y<u>IE</u>LD, C<u>EI</u>LING, DEBR<u>IS</u>, SC<u>E</u>N<u>E</u>). See also the discussion above on inconsistent spelling in English (p. 28).

In fact, compared with other alphabetic orthographies, English is one of the more complex. Spanish, which will be described next, is at the other end of the spectrum. It is considerably less complex.

2.2 The relative simplicity of Spanish orthography

In Spanish, the relationships between phonemes and graphemes are much more straightforward. For example, a vowel letter always corresponds to either a full vowel or a glide (e.g., TOALLA /toaja/, SIESTA /sʲesta/). Spanish has the consonant digraphs CH, GU, LL, QU, and RR, but it has no vowel digraphs. Alphabetic orthographies like Spanish are transparent, or shallow. They can be decoded with knowledge of just a few GPCs. Because of this, orthographic rimes also consistently represent the phonology of words, but they provide no particular advantage over graphemes.

On the surface, the vowel pairs UE and UI appear to be digraphs when they follow Q or G (e.g., QUITAR, pronounced /kitaɾ/). But their status is ambiguous. The relevant letter pairings are much more likely to be QU and GU since these are more consistent than the vowel-letter pairs. The letter Q never occurs without the letter U, and the letter pair GU signals a dependency rule between itself and the vowel that follows. Specifically, if GU is followed by A or O, the U is pronounced as the diphthong /ʷ/ (e.g., GUANTES /gʷantes/). But if GU is followed by E or I, then the U is silent (e.g., GUISO /giso/). Finally, the vowel pairs UI and IU do appear in other contexts as independent phonological units (e.g., CUIDADO /k^widado/, CIUDAD /s^judad/). Thus, the pairs UI and IU do not seem to be digraphs, whereas QU and GU do.

It is important to note, however, that written Spanish is more transparent in reading than in spelling. That is, identifying and/or pronouncing written words in Spanish is fairly easy, but spelling them can be more difficult. For example, the word /s^jelo/ might be spelled CIELO (the correct form), or misspelled as SIELO, or even ZIELO (in Latin American dialects).

It is easy to see the main differences between the English and Spanish alphabetic orthographies. English is more complex. This difference will inform predictions about the experiments presented in this dissertation (Section 3.3). For now, I turn to some of the research concerning literacy development, which must inform theories of how adults read (Castles, Davis, & Forster, 2003; Jackson & Coltheart, 2001; Rayner et al., 2001; Ziegler & Goswami, 2005), and in this case, how adults perceive graphemes.

2.3 Graphemes in current models of literacy development and reading

The literature concerning how children learn to read alphabetic orthographies is vast and refers to multiple models. I will cover three models of literacy development, and end with a model of adult reading: (a) Jackson and Coltheart's (2001) developmental dual-route cascaded model of reading; (b) Ehri's (1999, 2002) phase model of learning to read words; (c) Ziegler and Goswami's (2005) psycholinguistic grain-size theory of reading and literacy development; and (d) the parallel-distributed processing (PDP) model of Plaut, McClelland, Seidenberg, and Patterson (1996).

These models are arranged on a continuum roughly reflecting their respective flexibility regarding the basic perceptual unit of reading in alphabetic orthographies (for a comprehensive review of this issue, see Vellutino, 1982). At one extreme, Jackson and Coltheart (2001) claim specifically that abstract letter units are the basic perceptual unit from which all other representations in the reading system are derived. This is a widely accepted view. At the other extreme, Plaut et al.'s (1996) PDP model of adult reading suggests that the basic units are graphemes, and crucially not letters. The other two models of literacy development, Ehri's (1999) phase model and Ziegler and Goswami's (2005) psycholinguistic grain-size theory, lie in between. Both leave open the possibility that graphemes could supplant abstract letter units as the basic perceptual reading units. Ehri's phase model is important because of its influence, and Ziegler and Goswami's model is important because it may be the only one that was explicitly designed to accommodate orthographies other than English (though see Ziegler, Perry, & Coltheart, 2000, for an attempt to extend the dual-route model to German). At the end of this section, I will compare the four models. The first and third models (Jackson and Coltheart's model and Ziegler and Goswami's model, respectively) receive the most attention since they most clearly lead to different conclusions about the grain size of visual word recognition, which is central to this dissertation.

2.3.1 The dual-route, cascaded model

Dual-route models of word recognition and naming have been advocated for over a century, and are currently dominant in the literature (Coltheart et al., 2001; Jackson &

Coltheart, 2001; Lukatela & Turvey, 1998). Dual-route models hold that there are two ways to recognize or name words. This basic architecture is represented in Figure 2 below. One route in the general model operates by calculating the pronunciation of orthographic units. This is called the nonlexical, or indirect route, and is represented by the upper arrows in Figure 2. The other route in the general model operates by memorizing (for lack of a better term) all the letters in that word in an orthographic lexicon, and associating that letter pattern with an entry already established through normal linguistic development in the phonological lexicon. This is called the lexical, or direct route, and is represented by the lower arrows in Figure 2.

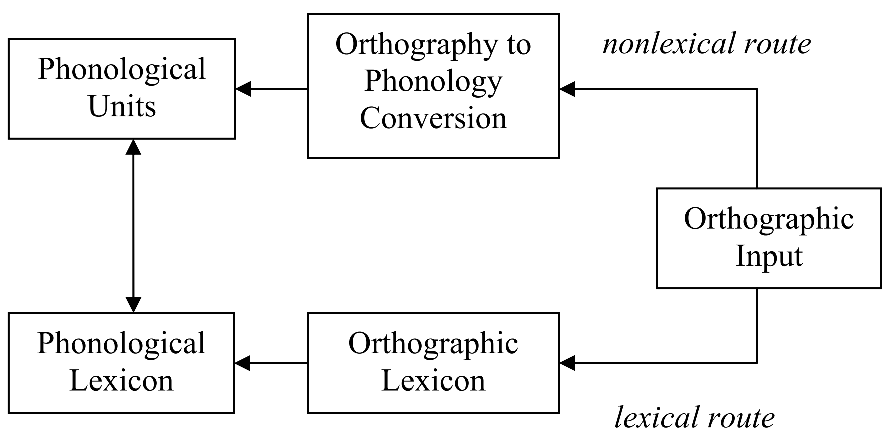

FIGURE 2. General dual-route architecture.

The justification for dual-route models in general is based on a variety of psycholinguistic findings. One consistent finding that supports dual-route architecture comes from experimental research with normally reading adults. It has been known for some time that low-frequency words take more time to name than high-frequency words (Forster & Chambers, 1973; Frederiksen & Kroll, 1976). If all that is required to name a regular word is to convert the letters into graphemes and the graphemes into phonemes, then there should be no difference in naming times between high- and low-frequency words. To explain the difference, the standard dual-route account stipulates that the orthographic lexicon is sensitive to frequency, with high-frequency words accessed more quickly than low-frequency words. The logic is that the orthographic lexicon is large, containing all the words that any particular person can identify through print, and such a large inventory must be organized for efficient processing. Otherwise, every word in print would invoke a very time-consuming, perhaps random, search through every entry in the orthographic lexicon. Since the frequency effect is one of the most consistent findings in word-recognition research (Taft, 1991), it makes sense to posit that the orthographic lexicon be organized somehow by frequency. Low-frequency words take more time to access along the lexical route, enough time such that activation is no faster than it is via the slower, nonlexical route.

The developmental dual-route cascaded model (Jackson & Coltheart, 2001) is a natural descendant of Coltheart's dual-route cascaded (DRC) model for proficient readers (Coltheart *et al.*, 1993; Coltheart et al., 2001). I will describe the DRC for proficient readers first, which is depicted below in Figure 3.

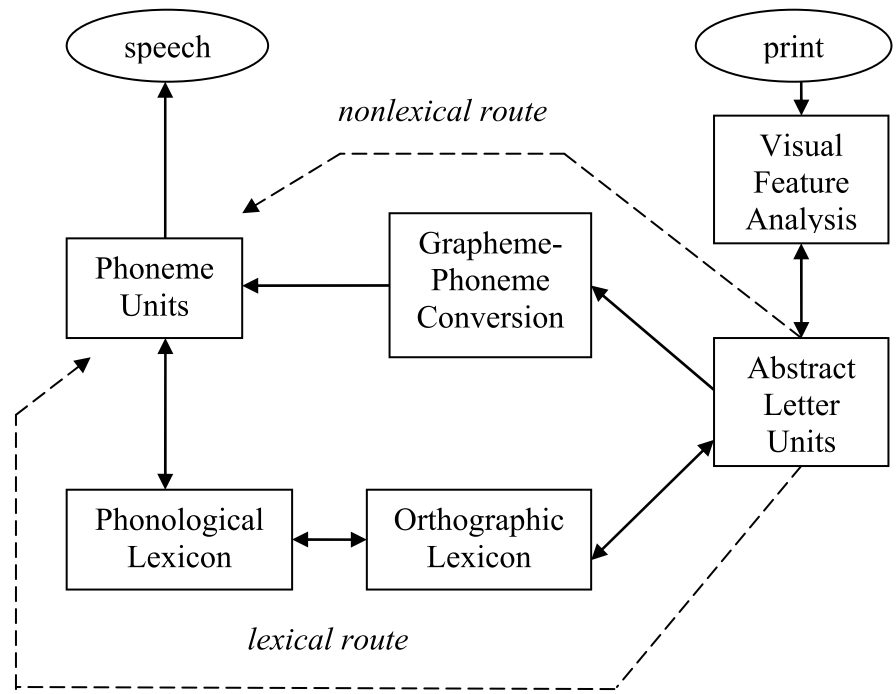

FIGURE 3. The dual-route cascaded model of reading and reading aloud, adapted from Jackson and Coltheart (2001).

Just as in the general dual-route model, Coltheart's DRC (2001) for proficient readers has two mental routes to word recognition: a grapheme-phoneme conversion route (the upper half of figure 3 and a whole-word route (the lower half of Figure 3). The DRC works initially by converting visual input stimuli into abstract letter units through a visual feature analysis, seen in the upper right-hand corner of the figure. This is so that a letter written in different ways can be recognized as the same unit (e.g., A, A, a, and a are all the same abstract letter: A). This stage in the process is quite central to this dissertation. Some researchers have suggested that it may not be abstract letters at this stage, but abstract graphemes. For now however, I will continue with the description of the other stages of the DRC, which will also turn out to be important for this dissertation.

Abstract letters then embark on two different paths simultaneously: the lexical and nonlexical routes. Letters enter and exit each of these initial modules one by one, making the model *cascaded* and *serial*, respectively. This cascading is done from left to right in English. This is depicted in Figure 4 below using the example PINT. Cascading refers to the fact that each letter moves on to the next stage once it has any activation in the previous stage. The term *serial* represents the fact that this is done in a linear fashion, from left to right through the sequence of letters in a word. For example, in the printed word PINT, the first letter to be activated would be P. This letter would then move on to the lexical and nonlexical routes simultaneously. Some fraction of time later, the letter I would follow right behind P. These are followed, of course, by N and T.

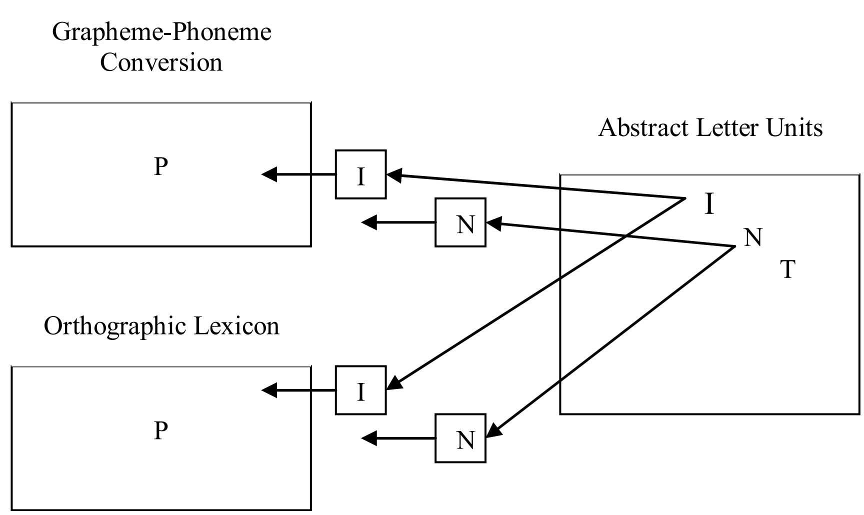

FIGURE 4. Serial and cascaded elements of letter activation in the DRC for proficient readers.

The lexical route combines elements of the logogen model of Morton (1969), and the interactive-activation model of McClelland and Rumelhart (1981). This route relies, on the one hand, upon excitatory connections between abstract letters and memorized letter strings (words) in the orthographic lexicon, and, on the other, upon inhibitory connections between all words in the lexicon. During any attempt to recognize a word, all the position-specific abstract letter units in a letter string activate all the lexical candidates in the orthographic lexicon having that same position-specific letter. This results in a very large number of lexical candidates. To narrow the set of candidates, the candidates themselves inhibit all other lexical candidates. Within some fraction of a second, these excitatory and inhibitory processes work together to bring a particular word above a certain threshold level of activation in the orthographic lexicon. Once a word reaches this threshold level of activation, it is recognized, and it, in turn, activates a corresponding word in the phonological lexicon through a single direct connection. In tasks requiring utterances, the activation then continues on to phoneme units and then articulated output.

The nonlexical route converts abstract letter units into graphemes and then phonemes (GPC conversion) in order to either pronounce them or compare them to a phonological lexicon for word recognition. The GPCs that operate in this stage are the correspondences with the highest frequency in the language. That is, any particular GPC rule in this module will be the association of a particular grapheme and the phoneme with which it most often occurs. For example, the consonant digraph CH will be associated with the phoneme /tʃ/. Those with lower frequencies (e.g., CH → /k/, as in CHAOS, CHIMERA, or CH → /ʃ/, as in CHIVALRY) are not represented since they would compete with highest frequency GPC.

Importantly, multi-letter elements that correspond to phonological elements larger than the phoneme (e.g., rimes, syllables) are not included in the DRC for proficient readers. This characteristic of the DRC is a point of mild contention, even among some of its advocates. Such units are not necessarily problematic for the DRC for proficient readers, but they have not been incorporated at this point for reasons of parsimony (Coltheart et al., 2001).

Sufficient activation along either route can lead to the identification and pronunciation of a written word, but the two routes differ in several important respects. Only the nonlexical route can identify previously un-encountered written words (e.g., CALLOSUMECTOMY for most adult readers of English). And it is the only part of the system that can pronounce nonwords (e.g., GLIMP).[12] In contrast, since the lexical route points to a lexicon based on the orthographic forms of entire words that have already been encountered and memorized, only this route can identify exception words (e.g., HAVE, PINT, EPITOME, TONGUE).

Several findings have been crucial to the evolution of the DRC for proficient readers. One has sparked a debate important to this dissertation. Rastle and Coltheart

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[12] The letter strings CALLOSUMECTOMY and GLIMP would both appear to be nonwords to a anyone who had not encountered CALLOSUMECTOMY before.

(1998) had participants name nonwords that had the same number of letters but varied in the number of graphemes. For example, PHING and BLASK have five letters each. But the three phonemes of PHING are represented by three graphemes (PH, I, and NG), whereas the five phonemes of BLASK are represented by five graphemes (the five letters in BLASK). Rastle and Coltheart found an increase in naming times for the words with fewer graphemes. This finding can be explained in the DRC for proficient readers. As described above, abstract letters in this model feed into a GPC module one at a time from left to right. The GPC module assumes at first that each letter corresponds to a phoneme. Increases in naming times occur when the module encounters letter combinations that cannot be, or are not normally, pronounced separately. Examples would be PH and EA. During the resolution process, graphemes with more letters compete for activation with graphemes with fewer letters. This competition takes time. This cost in time accounts for the longer naming times. Rastle and Coltheart called this the *whammy effect*. Importantly, this increase in naming times is an entailment of the model using letters as input. Rey et al. (2000) took issue with this claim and suggested that graphemes are the basic grain size of visual word recognition, not letters. The experiments of Rey et al. are covered at the end of this chapter.

Jackson and Coltheart (2001) put forward a version of the DRC that would apply to developing readers. The developmental DRC has essentially the same architecture as the version for proficient readers. It simply lacks specification in the various modules.

What follows is a summary of Jackson and Coltheart's proposal as to how a pre-reader might become a proficient reader (Jackson & Coltheart, 2001).

Jackson and Coltheart (2001) argue that all components of the DRC for proficient readers are probably available in elementary form to the normally progressing child at about the time she begins to read. But some components of the system are much more available to the child than others. For instance, all normally progressing children in the early stages of learning to read have a very well-established phonological lexicon (usually around age 5 or 6). That is, normally developing children will be able to identify a very large number of words when they hear them. Additionally, they have a well-established semantic system, which they can use not only to communicate meaningfully with other people, but also both to infer the appropriate meanings of new words, and to distinguish among closely related words. Finally, by this age, they should have adult-like knowledge of the phonemic inventory of their first language (Gerken, 1994), although they are not usually consciously aware of this knowledge.

Other components of the DRC are available but probably less well elaborated in young readers. The ability to derive abstract letter units is one example. Most beginning readers can name the uppercase letters of the alphabet, and they quickly learn to identify upper- and lower-case forms as referring to the same letter.[13] Jackson and Coltheart (2001) propose that early readers can identify letters in an abstract sense even though

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[13] In fact, knowledge of letter names among pre-readers is highly related to later success (Adams, 1990).

they may not be able to form them into words (see also Treiman & Kessler, 2004). This is a key ability since the abstract letter unit is the key to the rest of the DRC (Jackson & Coltheart, 2001).

Another major component of the DRC that is probably available to beginning readers in elementary form is the lexical route. Jackson and Coltheart's (2001) suggestion here is based on two observations in the literature. First, pre-readers can often identify a small number of short, familiar words, especially their names, even when they cannot pronounce new ones (Share & Stanovich, 1995). This is only possible if they have formed connections between the full orthographic form of the word (or parts of it) and both its meaning and its pronunciation. If they understood the sublexical components of these words and what they stood for, they could make better guesses at new words. Second, when trying to identify new words, pre-readers often err by identifying another word that is close to the target word in orthographic form (Ehri, 1999). According to Jackson and Coltheart (2001), this tendency can be explained easily by the developmental DRC: The child is making a close, albeit incorrect, match to a word in her orthographic lexicon, and then retrieving the phonology of that misidentified word through a link with the phonological lexicon. This sort of error would not occur on a model in which only the nonlexical route was active. Errors would be on near-phonological matches, not near-orthographic matches.

Jackson and Coltheart (2001) also suggest that children learning to read can exploit a rudimentary nonlexical route. Children in kindergarten and first grade can often accurately pronounce two- to three-letter pseudowords (Thompson, Cottrell, & Fletcher-Flinn, 1996). But the elaboration of this route to the point where it will be useful for such purposes as reading aloud fluently, or quickly identifying new words, will take at least a couple more years.

A general difference between the developmental DRC and the models that follow is the degree of inherent specification prior to and during literacy development. The architecture of the DRC for proficient readers is quite elaborate and explicit. As explained above, Jackson and Coltheart (2001) claim that children inherit this architecture of the DRC before they learn to read, and its nature does not change over the course of literacy development. The system changes only with respect to the degree of specification within the modules in the architecture.

A more specific difference between the developmental DRC and the models that follow, however, has to do with the most fundamental abstract reading units. Recall that the basic reading unit in the DRC is the letter. In contrast, the models that follow do not necessarily make this assumption. They are more malleable over time, particularly in terms of which linguistic units are fundamental to literacy and the adult reading system.

2.3.2 The phase model

Ehri's (1999) model of reading development has become very influential recently. On her model, developing readers proceed through four phases. In a sense, it is a bottom-up developmental model in that children begin with small units in the orthography (e.g., letters), and later learn to use larger units (e.g., onsets and rimes) to recognize words.

In the first phase, readers use non-alphabetic, or visual information to recognize words. Thus, these readers might relate the vowels in the word LOOK to two eyes looking out from the page. At this point, these readers are not using alphabetic knowledge, per se. But they are beginning to distinguish different letter patterns. Ehri (1999) calls this the pre-alphabetic phase. Skills learned here will help bring these readers to the next phase of development.

In the second phase, readers begin to identify words through incomplete knowledge of letters (e.g., letter names and canonical sounds). This is the partial alphabetic phase. Readers in this phase often fail to identify words accurately, but the wrong word is close in form or sound. Thus, such readers might read TOE as TOP, or SNAIL as SNIFF.

In the third phase, readers are able to decode all regular words and nonwords accurately. This is the full alphabetic phase. In this phase, readers do not confuse words with similar spellings. Such readers also have an advanced sight vocabulary for high frequency and exception words. For all intents and purposes, these readers are literate.

Importantly for this dissertation, readers in this phase possess knowledge of how multi-letter graphemes correspond to single phonemes. Moreover, word recognition at this stage, even for fully memorized words, always requires sublexical phonology. Ehri (1999) states,

> [B]eginners remember how to read sight words by forming complete connections between letters seen in the written forms of words and phonemes detected in their pronunciations... (p. 92) According to our theory, the same types of connections are formed for irregular words as for regular words since most of the letters in these words can be connected to sounds… (p. 95).

Thus, Ehri's model is a strong phonological model if she means that phonology must be invoked in order for readers to recognize words.

The last phase is the consolidated alphabetic phase. According to Ehri (1999), a reader in this phase continues to analyze written words into ever higher-order linguistic units as appropriate in the orthography. For instance, such readers will begin to categorize written words into orthographic-rime families (e.g., GIFT, RIFT, SIFT, LIFT). Such readers may also categorize written words into morphological-root families such as SIGNATURE, ASSIGN, SIGNAL, SIGNIFY. Knowledge of these units is learned through exposure to more and more print. This knowledge results from subconscious, automatic analysis of word patterns that either never completely settles on a fixed representation of the written language, or only does so very late in reading development.

Ehri (1999, 2005) suggests indirectly that visual units become less and less relevant over time as phonological units become more basic to the system. For example, states the following about her theory:

> In phase theory, the sound mapping function of letters is emphasized and their visual form is slighted in explaining how beginners in the partial and full alphabetic phases form connections to store words in memory when they read them. (Ehri, 2005, p. 181)

These units are restricted to graphemes until the consolidated alphabetic phase where larger grain sizes are introduced. Repeated exposure to GPCs could make graphemes perceptually fundamental on her model. This is speculative, but if true, it would make her model contrast sharply with the developmental DRC, where the fundamental unit of word recognition is always the abstract letter unit.

2.3.3 The psycholinguistic grain-size theory

Ziegler and Goswami's (2005) psycholinguistic grain-size theory (a model) argues that literacy development depends not only on the phonological structure of the language being read, but also on its particular orthographic structure. The script-dependency of this model contrasts with the models presented thus far. A script-dependent model of literacy development, following Geva and Siegel's (2000) classification, emphasizes the role that different orthographies can play in literacy development. In fact, several researchers have begun to investigate whether and how different scripts affect literacy development (e.g., Ellis & Hooper, 2001; Frith, Wimmer, & Landerl, 1998; Frost, 1994; Geva & Siegel, 2000; Harris & Hatano, 1999; Katz & Frost, 1992; Paulesu et al., 2001; Taylor & Olson, 1995).

The psycholinguistic grain-size theory incorporates these studies and works in the following way. Ziegler and Goswami (2005) start with pre-readers. Long before they begin to read, children become familiar with their particular spoken language. As they do so, common syllabic units in that language repeat themselves. For instance, some languages allow complex, closed syllables. In such languages, there tends to be a wide variety of rimes. In English for example, certain rimes repeat themselves in large word families (e.g., words phonologically ending with /id/: BEAD, BREED, BLEED, CEDE, CREED, DEED, FEED, GREED, HEED, LEAD, NEED, PLEAD, REED, SEED, SPEED, STEED, WEED). According to Ziegler and Goswami, the repeated element, the rime, then becomes salient to the young English speaker.

But in languages where most syllables are open (i.e., do not end with consonants), the most salient syllabic unit is the nucleus with or without an onset, excluding the coda. Examples are the /pʷe/ and /to/ in the Spanish word PUESTO /pʷes.to/). Languages with mostly open syllables include Korean, Japanese, Italian, and Spanish. Ziegler and Goswami (2005) claim that it should be useful to a child learning Spanish to organize her lexicon at least in part on vowel nuclei and onset-nuclei pairs. By doing so, these sub-syllabic units should become salient to the child before she begins to read.

For Ziegler and Goswami (2005), then, all children are naturally aware of syllabic units in the spoken language before they begin to read, and they begin the reading task with a predisposition to analyze words into syllable units. In alphabetic orthographies, this sets up a conflict between what the child will naturally hypothesize and what she must learn.

The conflict is the following: Natural phonological awareness supports large grain sizes like the rime (in English) or the onset-nucleus unit (in Spanish), but orthography supports small grain sizes like the phoneme. When children begin learning to read in an alphabetic orthography, they will eventually have to realize that letters stand for something other than syllable units. Not to do so would be disastrous of course. This realization, in turn, drives phonological awareness at the level of the phoneme (phonemic awareness). Thus, phonemic awareness develops only, or mostly only, when they begin to read. Ziegler and Goswami (2005) are joined by other researchers in their view of phonological awareness developing from large to small phonological units (e.g., Bentin & Leshem, 1993; Carroll, 2004; Holm & Dodd, 1996; Loureiro et al., 2004; Morais, 1987; Morais et al., 1979; Wimmer et al., 1991).

This conflict between natural phonological awareness at the syllable level and learned phonological awareness at the phoneme level leads to roughly three rates of initial literacy development, depending on the language. These rates are most properly conceptualized along a continuum, but following Ziegler and Goswami (2005), I present them as categories for ease of clarification. For languages that have mostly open syllables and a shallow orthography, initial literacy development is rapid, and the grain size of word recognition tends to resolve at the letter level. Children learn to read well within a few months of literacy instruction (Cossu, 1999; Goswami, Gombert, & de Barrera, 1998). This is because the natural phonological awareness of the syllable and the learned phonological awareness of the phoneme overlap quite well. In Spanish for example, the word TOALLA has three open syllables /to/, /a/, and /ja/. In the first syllable, the onset /t/ and the nucleus /o/ both overlap perfectly with the letters T and O. Most syllables in Spanish are like this, so the child learning to read would have little reason to seek correspondences between spoken and written units other than the ones she is already aware of (syllable parts) and learning (letters). Indeed, to the reader of Spanish, sub-syllabic units and letters are mostly the same. That is, the onset is the same as a letter, and the nucleus is the same as a letter. These are one-to-one associations between letters and a child's natural phonological awareness of the syllable. Of course, Spanish has complex (multi-consonant) onsets, as in the first syllable of PLAYA /pla/, and a few codas, such as in PAN /pan/ and PAZ /pas/. Thus, the overlap is not perfect between syllable units and letters, but Ziegler and Goswami argue that the overlap is sufficient to make initial literacy development rapid.

When shallow orthographies apply to languages with complex syllable structure (e.g., many complex onsets and codas), initial literacy development is also quite rapid, though not as rapid as in languages with simpler syllable structure. Examples of these languages are German and Dutch. In such languages, the child's natural phonological awareness of sub-syllabic units (rimes in this case) does not overlap with the structure of the orthography since more often than not, multiple letters correspond to single sub-syllabic units. For example, the onset and rime of the German word SCHLECT are SCHL-

/ʃl/ and -ECHT /ɛxt/, respectively. In this example, the onset and the rime are each represented by four letters. These one-to-many relations between syllable units and letters are common in German and Dutch, so the child learning to read will spend relatively more time reconciling the fact that letters do not represent syllable units. In this way, phonemic awareness becomes more important for readers of such languages than for readers of languages such as Spanish. Such associations are harder to infer than one-to-one associations. But since German uses a shallow orthography, once the child learning to read acquires some phonemic awareness by figuring out that the letters tend to represent phonemes, she will have less trouble decoding new words and nonwords. However, since German and Dutch contain many multi-letter graphemes, the children will need even further time to infer these relations.

According to Ziegler and Goswami (2005), languages with deep orthographies and complex syllable structure present yet another problem altogether. Initial literacy takes longer in these contexts. Children learning to read these languages, like those learning to read German and Dutch, will need to become aware that letters do not represent syllable units, which will take time. But unlike German and Dutch, deep orthographies exhibit a considerable amount of inconsistency between graphemes and phonemes. For instance, in the word THREAD, the EA digraph does not represent the phoneme /i/, like it normally does. Instead, it represents the phoneme /ɛ/, which is a less common association. The presumed inclination of young readers to seek consistency between the orthography and phonology will lead them to seek more reliable associations between letter sequences and linguistic units at higher and higher levels. This process will continue until sufficient or maximum consistency is found. In the case of the example THREAD, the child will eventually learn that the phoneme /ɛ/ is not as uncommon in the orthographic rime -EAD (e.g., BREAD, BREADTH, DEAD, DREAD, HEAD, SPREAD, INSTEAD, TREAD). But since there are always more units at larger levels (i.e., more syllables than letters, more morphemes than syllables, more words than morphemes), this process will take more time than in the other two contexts.

As illustrated at the beginning of this chapter, English is an example of a deep orthography. Its syllabic structure is much like that of German and Dutch, but correspondences between its graphemes and phonemes are inconsistent. Ziegler and Goswami (2005) argue that the reader's inclination to seek consistency in the orthography explains why children learning to read English lag behind their Spanish and German counterparts in reading words and nonwords accurately. They refer to the report by Seymour et al. (2003) on a large-scale study conducted in Europe. This study showed that at the end of one year of reading instruction, children learning shallow orthographies (e.g., Spanish) were highly accurate in word and nonword reading (around 90-98%), but that those learning deep orthographies (e.g., English, French, Danish) were far less accurate (around 30-70%, with English at the lowest end). Other researchers have also reported that literacy development in shallow orthographies tends to be faster and easier than in deep orthographies (e.g., Bentin, Hammer, & Cahan, 1991; Cossu, 1999; Frith, Wimmer, & Landerl, 1998; Goswami, Gombert, & de Barrera, 1998; Harris & Hatano, 1999).

But most importantly, the psycholinguistic grain-size theory captures a missing developmental link between letters and graphemes. Recall one of the basic claims of this model. The letters in alphabetic orthographies motivate early readers to develop phonemic awareness so that they have something to associate with what they are seeing. And when these early readers find inconsistencies between letters and phonemes, they seek larger linguistic units (e.g., rimes) to associate with larger letter groups until maximal consistency is achieved. But letters are also inconsistent with phonemes, at least to some degree, in almost all alphabetic orthographies.[14] So on the same model, it must be assumed that early readers also appeal to graphemes in order to establish consistency in the orthography. This, in turn, implies that graphemes are potential reading units. Thus, the psycholinguistic grain-size theory provides a mechanism for the early reader to switch from using letters to using graphemes as fundamental perceptual reading units in visual word recognition.

Ziegler and Goswami's (2005) do not argue that early readers in English learn to choose particular word-recognition units in lieu of others, or that such word-recognition units apply across the lexicon systematically. Rather, early readers identify consistent relations between the orthography and the phonology of particular words, and then they

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[14] A notable exception is Serbo-Croatian, which has one-to-one letter-to-phoneme correspondences (Frost, Katz, & Bentin, 1987).

learn to apply this knowledge automatically in a parallel, non-hierarchical fashion. Ziegler and Goswami claim that this makes their model compatible with parallel-distributed processing models (p. 20), which are described next.

2.3.4 Grapheme-based parallel-distributed processing

Parallel distributed processing (PDP) networks are connectionist computer models of learning. For the past 25 years or so, certain researchers have appealed to connectionist modeling, in limited ways, to explore how much language learning might be achieved through general learning mechanisms rather than through innate mental modules designed to handle the process (e.g., Bates & MacWhinney, 1982; McClelland & Rumelhart, 1985; Plaut et al., 1996; Rack et al., 1994; Seidenberg & McClelland, 1989). The original connectionist networks were *localized*. The goal of researchers in this paradigm was to create computer programs that could learn to identify or pronounce linguistic units (usually words) that were assumed to be stored independently in the mind (i.e., localized). PDP networks take connectionism one step further and do away with localized representations altogether.

In PDP networks, words are simply weighted connections between various isomorphic linguistic features. In this way, words are distributed representations rather than localized representations. In the first PDP network of its kind, which targeted reading and literacy, Seidenberg and McClelland (1989) used three levels of representation: orthography, semantics, and phonology. Each of these levels contains many units (e.g., phonemes in phonology, semantic features in semantics, and letters in orthography). Through weighted connections, units at each level interact independently with units in each of the other two levels. This makes the network parallel in nature. This architecture is depicted below in Figure 5.

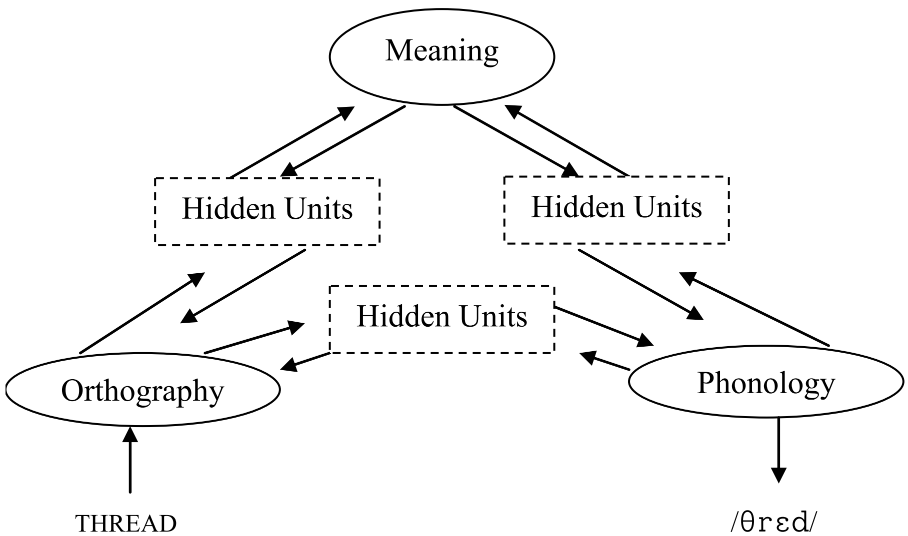

FIGURE 5. The triangle network of lexical processing (adapted from Seidenberg & McClelland, 1989).

As the network evolves, hidden units (represented as dashed boxes in Figure 5) that lie between each level of representation (represented as ovals) adjust connection weights (represented as arrows) between units based on whether a particular combination of weights was sufficient to carry out some task accurately (e.g., naming). With phonology for instance, as graphic units feed into the computer network (three orthographic units at a time in the Seidenberg and McClelland (1989) version of the network), the network tries to assign appropriate phonemes. The example in the figure is the exception word THREAD. When the network generates the incorrect pronunciation for a letter string (perhaps /θrid/), the hidden unit between orthography and phonology weakens those connections between the respective letters and phonemes. When the network succeeds, the hidden unit strengthens the connections (e.g., between the letter string and /θrɛd/). This process continues until either the network peaks in terms of efficiency (however efficient that may be), or some pre-determined amount of time expires. The success of the network in modeling human behavior is judged in terms of how well it can imitate research results using human participants. According to PDP advocates, when any particular PDP network can replicate the findings with humans reasonably well, that network will be a legitimate description of written word recognition.

One of the problems with the original PDP network (Seidenberg & McClelland, 1989) was that it was unable to name nonwords like humans can, though it imitated 20 other well-known word-recognition results with human participants (Plaut et al., 1996). Plaut et al. argued that this was an important limitation for the following three reasons. First, the addition of the semantic level of representation to the network was not likely to improve nonword reading. Second, the weakness at nonword naming prevented the authors from comparing the model to the research on dyslexia that involved nonword reading. And third, if the network could not read nonwords, then the PDP model could not challenge dual-route architecture since dual-route models were designed, in part, to explain the fact that people can accurately pronounce nonwords.

In an attempt to address these shortcomings, Plaut et al. (1996) made a significant change to Seidenberg and McClelland's (1989) network. Their revised network could accurately name nonwords if, in the network's training phase, the orthographic inputs were in the form of graphemes, not individual letters.[15] In explaining their decision to include graphemes, they suggested children may treat letter patterns like "visual objects," eventually developing "explicit representations... for letter combinations that occur often or have unusual consequences." (p. 67)

Importantly, the Plaut et al. (1996) network leaves no room for processing letters, per se, except insofar as they happen to be equivalent in form to graphemes (i.e., single-letter graphemes). On this model's definition, graphemes are the basic perceptual unit of visual word recognition and naming, not letters.

2.3.5 Comparing the four models

Jackson and Coltheart's (2001) developmental DRC differs from Ehri's (1999) phase model in an important respect. Neither the DRC for proficient readers nor the developmental DRC has any place for representation of units larger than the phoneme or grapheme. Coltheart's models reject orthographic rimes and morphemes as visual word-recognition units or units important in naming (Coltheart et al., 2001; Jackson & Coltheart, 2001).[16] The basic grain size of visual word recognition and naming is the

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[15] In the original model by Seidenberg and McClelland (1989), the input units were context-sensitive *wickelgraphs*. Wickelgraphs are all possible, serial, three-unit members of a word, including spaces. For example, the set of wickelgraphs for the word POST would be _PO, POS, OST, and ST_.

[16] Coltheart et al. (2001) and Jackson and Coltheart (2001) are, in fact, flexible on this issue. They acknowledge that the basic grain size (or sizes) of visual word recognition is an open question, but only after abstract letter units are perceived.

individual letter in the DRC. Graphemes are always calculated from letters after letters are perceived. But as noted above, readers in Ehri's consolidated alphabetic phase continue to analyze written words well after the full-alphabetic phase in order to make word recognition more efficient. On the phase model therefore, the grain size of visual word recognition and naming can change over time. And according to Ehri, it becomes larger over time in English (1999, 2005). Furthermore, since Ehri's model is strong phonologically, it stands to reason that consolidation should apply to the grapheme-phoneme correspondences (GPCs) as well. That is, if orthographic rimes are to be encoded in order to make word recognition more efficient, there is no plausible reason to exclude GPCs from this process. Thus, there is some reason to believe that Ehri's model requires that graphemes will eventually become basic units for visual word recognition and naming.

Ziegler and Goswami's (2005) psycholinguistic grain-size theory is similar to Ehri's (1999) phase model in terms of how the reading system ultimately matures for English. Like the phase model, the psycholinguistic grain-size theory also accepts that levels of representation beyond the letter may play a role in word recognition and naming. The two models differ only in terms of when the reader acquires these units. Simply put, intermediate units of word recognition become available much earlier in the psycholinguistic grain-size theory than on the phase model. This might have implications for the results with the child participants in my experiments. For adults, the differences between Ziegler and Goswami's model and the DRC for proficient readers are the same as those between Ehri's phase model and the DRC. The psycholinguist grain-size theory predicts that graphemes could become fundamental reading units; the DRC prohibits this.

Lastly, with respect to the grain size of visual word recognition, the two models that differ the most radically are Coltheart's DRC (Coltheart et al., 2001; Jackson & Coltheart, 2001) and Plaut et al.'s PDP model (1996). In short, the DRC is based on abstract letter units, while Plaut et al.'s PDP network is based on graphemes. Although Plaut et al. dedicated very little effort to justifying the use of graphemes as basic perceptual units, they stated that it was plausible to do so (pp. 64-67). Other researchers since have begun to pave the way for such a justification, including Ehri (1999) and Ziegler and Gowami (2005), though the justifications are only implied by their models.

Finally, it is useful to compare Plaut et al.'s (1996) PDP network with both Ziegler and Goswami's psycholinguistic grain-size theory (2005) and Ehri's phase model (1999). Recall that Plaut et al. do not discuss how reading development would instantiate graphemes as perceptual reading units, though they do recognize the problem. But such development could plausibly take place in the psycholinguistic grain-size theory just as it would in a PDP network. Indeed, Ziegler and Goswami claim that children learn to decode words much like a PDP network would. That is, when a child reads any particular letter string, she makes a best guess as to its meaning or pronunciation. When she is wrong, she adjusts the letter string's associations with semantic or phonemic features. She will peak when all the associations are correct. In a shallow orthography, she would reach peak efficiency in a fairly short time. In a deep orthography however, she would take more time. Furthermore, in the mental pursuit of consistency, she will appeal to higher and higher levels of linguistic representation in a deep orthography. These would have to include graphemes, in my view.

My main reason for comparing these models was to highlight the fact that all of them, either explicitly or implicitly, include assumptions about the nature of the basic reading unit. The DRC (Coltheart et al., 1993; Coltheart et al., 2001) includes the assumption that letters are the basic reading units. The PDP model (as laid out by Plaut et al., 1996) includes the assumption that graphemes are the basic unit. The phase model (Ehri, 1999) and the psycholinguistic grain-size theory (Ziegler & Goswami, 2005) are vague regarding this point, but imply that graphemes could eventually supplant letters as the basic unit.

2.4 Selected findings

Another group of researchers have begun to question whether the abstract letter unit is really the basic unit of visual word recognition (Rey et al., 1998; Rey, Ziegler, & Jacobs, 2000; Ziegler & Jacobs, 1995; Ziegler, Van Orden, & Jacobs, 1997). They have not necessarlily supported any particular model; they have just highlighted empirical problems with the notion that letters are the basic reading unit.

The idea that graphemes supplant letters as the basic units of visual word recognition is an old suggestion from Gibson and her colleagues (Gibson, Osser, & Pick, 1963; Gibson et al., 1962; Gibson et al., 1972). I will refer to it now as the grapheme-as-percept view. Gibson et al. (1962) found that participants were able to recall the spellings of pronounceable nonwords (e.g., FLEND) better than the spellings of unpronounceable nonwords (e.g., MSUKP). The researchers hypothesized that perhaps letters were not what participants were remembering at all, but rather letter sequences that corresponded to phonemes (i.e., graphemes). But Gibson et al. (1970) found that prelingually deaf participants also exhibited this behavior. Since the prelingually deaf should not be able to form the phonological representations found in spoken English, Gibson and her colleagues revised their initial hypothesis and suggested that orthographic structure itself had been largely responsible for their initial findings.

Recent experiments have renewed interest in Gibson et al.'s (1962) original hypothesis. For example, Martensen, Maris, and Dijkstra (2003) chose Dutch to test how distorting the adjacency of digraph components in target items would affect lexical decision and naming times. If the two members of a digraph are processed separately, then distorting their adjacency should have no effect. But if they are processed together, then distorting their adjacency should have an effect.

They chose two different digraph types. One type was a context-dependent digraph, where the phoneme assigned to one letter is dependent on the letter that follows.[17] There is only one such dependency in Dutch: The letter C, when followed by the letter E or I, is pronounced as the "soft C" (i.e., /s/); when followed by A, O, or U, it is

[17] It is debatable whether this should be considered a digraph at all since, in the end, two letters represent two phonemes.

pronounced as "hard C" (i.e., /k/).[18] In fact, the researchers chose only stimuli with the hard C (i.e., word and nonwords targets starting with CA-, CO-, or CU-). The other digraph type was an independent phonemic digraph (the type described above in this dissertation, where the particular letter pair corresponds to a particular phoneme). In Dutch orthography, a vowel-letter pair corresponds unambiguously to one phoneme, the only exceptions being in some proper names. For example, the letter pair OO is always pronounced as /o/, and OE is always pronounced as /u/. Here, the researchers chose target items that started with a single consonant letter, followed by the vowel digraph (e.g., the word MOERAS, the nonword MOERIER).

In one manipulation, the researchers inserted slashes into both target types between the first and second letters (e.g., C//ORTEX, C//ORVAS for the context-dependent digraphs, and M//OERAS, M//OERIER for the independent phonemic digraphs). If the two members of context-dependent digraphs are processed together, then this distortion should affect reaction times and naming latencies to items with the context-dependent digraphs since the distortion occurs exactly where the phoneme-dependency rule is disambiguated (i.e., between the C and the vowel that determines its pronunciation). But this distortion should have no affect on the independent phonemic digraphs since this sort of digraph is independent of the letter that precedes it.

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[18] English of course has the same rule. An exception might be the word CELTIC (/sɛltɪk/ or /kɛltɪk/). English also has a palatalized variant of the soft C, as in ANCIENT /eʲnʃənt/.

In another manipulation, the researchers inserted slashes between the second and third letters (e.g., CO//RTEX, CO//RVAS, MO//ERAS, MO//ERIER). If the two members of independent phonemic digraphs are processed together, then this manipulation should slow reaction times and naming latencies to such targets, but have no effect on the context-dependent digraphs.

Martensen et al. (2003) found that the most significant interference occurred when independent phonemic digraphs (the double vowels) were distorted between the second and third letters (i.e., between the two vowels). This was true in both lexical decision and naming. All other effects, where they occurred, were less dramatic or less significant. Martensen et al. concluded that independent phonemic digraphs are clustered very early in the reading process, "probably… before phonemes are activated" (p. 393). This conclusion points to digraphs as percepts.

In an attempt to challenge Rastle and Coltheart's (1998) interpretation of the whammy effect,[19] Rey, Ziegler, and Jacobs (2000) had English and French participants search for particular letters in monomorphemic, monosyllabic words in their respective languages. Rey et al. reasoned that if graphemic representations are activated only after letters are perceived (as in the DRC), then the whammy effect should not appear in a letter-detection task, where no phonology is involved, ostensibly. In other words, if DRC

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[19] Discussed in Section 2.3.1 above, the whammy effect is the finding that it takes participants longer to name nonwords with fewer graphemes than nonwords of equal length with more graphemes.

architecture is correct, then participants should be able to make letter-detection decisions from abstract letters alone, without resorting to the lexical or nonlexical route.

Participants first saw a vowel letter, followed by a target word for 30 ms, then a blank screen for 70 ms, and finally a row of superimposed Xs and Os.[20] This manipulation gave the impression of a 100-ms target. The search letters were A, E, I, and U in experiment 1A, and A, I, and O in experiment 2 (the English experiments). The target words were of two types: 1) words containing the search letter by itself (e.g., in English, looking for A in BACK where A is the only vowel); and 2) words containing the search letter in a vowel digraph (e.g., in English, looking for A in GOAT where A is part of the vowel digraph OA).

Rey et al. (2000) found that both English and French readers took longer to detect letters in digraphs than in single-vowel graphemes. That is, it took them longer to respond to the letter A when embedded in GOAT than in BACK.[21] Importantly, there was no effect for word frequency in experiment 1A,[22] suggesting that "the grapheme effect is due to an automatic sublexical grouping of letters into multi-letter graphemes" (Rey, Ziegler, & Jacobs, 2000, p. B8). Presumably, the authors meant to exclude the possibility that participants executed this task along the lexical route. If it had been executed along this

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[20] The rapid presentation of the target word was meant to make the task more difficult (A. Rey, personal communication, November 25, 2003).
[21] The effect also remained when, in a follow-up manipulation, they removed the backward pattern mask and let the target word remain on the screen until a response was made (A. Rey, personal communication, November 25, 2003).
[22] This was also true for experiment 1B in French, which is not covered here. Experiment 2 did not include a frequency manipulation.

route, there should have been a frequency effect. Ultimately, they reasoned that the digraph effect follows if multi-letter graphemes, and not just single letters, are basic reading units. They state, "[Our results cast] doubt on the assumption that individual letters are the functional units of the adult reading system." (p. B7. If readers perceived words as strings of abstract letters (as in the DRC), they should have been as quick to detect A in GOAT as in BACK.

More specifically, Rey et al. (2000) explain this digraph effect as the result of competition among grapheme units. It is not abstract letters, per se, that are activated at the perceptual level (as in the DRC), but rather abstract graphemes. On Rey et al.'s view, all possible graphemes will be activated upon presentation of a written stimulus. For example, when a reader sees the word GOAT, the five graphemes G, O, OA, A, and T are all activated, not just the four abstract letters G, O, A, and T. The slowdown for digraphs relative to single-letter graphemes is the result of increased competition among grapheme units. Referring to the example above, the word GOAT activates five graphemes, whereas the word CLAN, for example, only activates four (C, L, A, N). Alternatively, GOAT activates three vowel graphemes (O, OA, and A), whereas CLAN activates only one (A). They explain Rastle and Coltheart's (1998) whammy effect in the same way. By virtue of activating more graphemes, nonwords with digraphs activate more phonemic candidates for naming than nonwords with single-vowel graphemes. Naming latencies are slowed when there are more phonemes competing for pronunciation.

To be fair, Rey et al. (2000) could have been proposing an extra stage of grapheme activation after initial letter perception. They are ambiguous on this exact detail. Nevertheless, their consistent claim that multi-letter graphemes act as the basic perceptual units of reading, and not letters, leads me to conclude otherwise.

But according to Rey et al. (2000), there was a weakness in their study. The presentation of the search letter in experiments 1A (English) and 1B (French) likely activated phonemic representations that were more similar to the vowels in single-vowel targets than to vowel-digraph targets. This is somewhat speculative since no one knows what sort of phonemic representations are activated when letters are presented in isolation. But it is likely true to some degree since the letters A and I each represent a word in English. The description of this confound is as follows. For YES responses, the pronunciation of the vowel in the single-vowel targets always corresponded to one of the canonical pronunciations of the search letter (e.g., A → stark /ɑ/, E → theft /ɛ/, I → shift /ɪ/, U → pluck /ʌ/). In contrast, the pronunciation of the vowel in the digraph targets did not always correspond to a canonical pronunciation of the search letter (e.g., A → poach /o/, I → waive /eʲ/, U → count /ɑʷ/).

Rey et al. (2000) responded to this weakness in the simplest way possible: by controlling for the phoneme that is identical to the name of the letter in experiment 2. They did this in English only since the manipulation was not possible in French. They chose single-vowel and digraph targets that contained vowels that either phonemically matched the name of the search letter or not. For the search letter A, for example, they chose single-vowel targets such as CRAVE and digraph targets such as BRAID, both of whose vowels are pronounced as /eʲ/. This pronunciation is equivalent to the name of the search letter. They also chose such single-vowel targets as TRASH and such digraph targets as FRAUD, both of whose internal vowels are different than /eʲ/.

They found that reaction times to A → CRAVE targets were still faster than to A → BRAID target (the "same phoneme" condition). Apparently however, there were no significant differences between A → TRASH and A → FRAUD targets (the "different phoneme" targets). Nonetheless, Rey et al. concluded that the digraph effect remained when phonemic similarity was controlled for. They held this up as a challenge to the operations of the DRC's nonlexical route. That is, the DRC could account for the whammy effect, but not the digraph effect in the Rey et al. (2000) experiments.

But it is not clear how this explanation rules out grapheme-phoneme conversion in the DRC. Surely, there could be a whammy effect for letter identification. This makes particular sense if one adopts the simple assumption that the reading system is automatic, and any non-normal task, like letter identification, will be subject to the same operations as normal reading. In other words, it is quite possible that the letter-identification task invokes the same phonological processes as reading aloud. In fact, a frequency effect, it seems, would have helped, not hurt, Rey et al.'s case. That is, if readers process abstract grapheme units (as opposed to abstract letter units) at the gateway to the dual route, then graphemic effects should appear just as, or more, robustly along the lexical route. Indeed, it would be extremely difficult for the DRC, as currently modeled with abstract letter units as the base, to account for digraph effects along the lexical route.

Rey et al's (2000) experiments are the foundation for my experiments. I will attempt to address two issues that the Rey et al. experiments could not address, and two more issues that the Rey et al. experiments were not designed to test. I mentioned these briefly in the introductory chapter. First, if the grapheme is a perceptual reading unit as Rey et al. claim, then their digraph effect should appear under conditions where the participant cannot make any conscious decision on the grapheme itself. But it is difficult to control for decision effects in an experiments like those in Rey et al. (2000), where the conditions are reflected in the targets on which the participants consciously make decisions. My experiments will rule out this possibility by preventing participants from making conscious decisions on the relevant experimental items. The answer will inform main problem laid out above in the discussion of the different reading models: Are letters or graphemes the basic perceptual reading units?

Second, although Rey et al. (2000) found the digraph effect in English and French, both those languages have vowel digraphs. One should test whether the effect occurs in a language with no vowel digraphs, but with monomorphemic, adjacent written vowels. Spanish is such a language (see Section 2.2 above). Rey et al.'s digraph effect should disappear in Spanish since Spanish readers would have no motivation to convert adjacent written vowels into graphemes. But it would be inappropriate to test Spanish participants using the design employed in Rey et al. for English and French participants. Their design would necessarily predict the null hypothesis in such a language whether one adopts a grapheme- or letter-as-percept view. There are no vowel digraphs in Spanish, so it would be unreasonable to predict digraph effects. But my experiments introduce changes that enable me to predict relevant, significant effects in Spanish despite the absence of vowel digraphs.

Third, I will look at how both English-dominant and Spanish-dominant bilinguals do on the task in both languages. This is to see how alphabetic processing knowledge in one language transfers to alphabetic processing in the other. If the experimental results differ between English and Spanish monolingual readers, then there is reason to believe that such letter knowledge in the dominant language, as measured by the test, will transfer to the less dominant language. This is because the letters in the two languages are sufficiently similar.[23]

Lastly, I will look at how early children begin processing letters and/or graphemes automatically. If adults show automatic letter processing at a subconscious level, then it is worth asking when this skill emerges during reading development. The skill should happen some time early in reading development.

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[23] Spanish does use a few diacritics like a tilde (Ñ), a dieresis (Ü), and accent marks (e.g., É), but I assume they are additions to the basic roman alphabet. Only the Ñ can be considered a grapheme in a fundamental sense. The others do not indicate any change in pronunciation, except at the stress level. Interestingly, English has also incorporated some diacritical marks, though they are not considered part of the alphabet (e.g., NAÏVE, BRONTË, CAFÉ, FAÇADE).

The changes to the Rey et al. (2000) experiments are covered in the next chapter. In addition, I will cover some basic experimental predictions.

CHAPTER 3 THE CURRENT STUDY

Masked priming is the ideal paradigm to investigate the question of whether letters or graphemes are the basic reading unit. The masked-priming technique has been used with reliable results on a variety of tasks (Forster, Mohan, & Hector, 2003; Kinoshita & Lupker, 2003).[24] The masked-priming paradigm permits me to modify Rey et al.'s (2000) experiments to do the following: (a) probe more confidently for automatic processing; (b) test the grapheme-as-percept hypothesis in a language without digraphs; (c) explore how alphabetic processing knowledge in a dominant language transfers to a less dominant language; and (d) investigate how early in reading development automatic alphabetic processing knowledge emerges.

This chapter begins with a detailed description of the masked priming paradigm. It is followed by an explanation of how my experiments are designed in general, using the adult English materials as examples. Finally, it covers predictions in both the Spanish and English experiments.

3.1 The masked priming paradigm

As mentioned in Chapter 1, the basic priming experiment involves the presentation of one stimulus before another. The goal is to see what effect the first

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[24] Letter detection with masked priming has been done before with some success. Unpublished research by Ken Forster and Chris Davis found reliable effects in a letter-detection task when the masked stimulus and target word shared a target letter (K. I. Forster, personal communication, November 25, 2003).

stimulus, the prime, has on the second, the target. In most priming experiments, participants ignore the primes and respond to the targets. In masked-priming experiments, primes are presented very rapidly with dissimilar stimuli, masks, before and after them. These two manipulations make it very difficult for participants to consciously perceive the prime. They naturally attend only to targets.

The key to a successful masked-priming experiment lies in the duration of the prime and the nature of the masks that come before and after it. This sequence is depicted in Figure 6 below, where each box represents a different stimulus on the computer screen. The mask that precedes the prime is called a forward mask. This is the first box in Figure 6. A common forward mask is a uniform pattern mask, having no linguistic relevance (e.g., #####). The forward mask gives the participant a region of the screen to focus on, and helps prevent conscious perception of the prime. It is important that the participant see the forward mask, so it is presented for a relatively long duration (e.g., 500-750 ms). The participant knows about this stimulus since he has been told to focus on it during instructions.

The prime itself is then presented for some short duration, usually 30-60 ms. this is represented by the second box in Figure 6. Traditionally, the prime is presented in lowercase letters (though it could be presented in uppercase or mixed case, i.e., MiXeD cAsE). If the prime is presented between the forward and backward masks with no delays between presentations, and its duration is not much longer than 60 ms, the exact form of the prime will be unrecognizable to most participants (Forster, 1998). In fact, the shorter the duration of the prime, the less likely the participant is to be aware of its presence at all. In this way, the prime is masked, or beyond at least the recognition if not the awareness of most participants (Forster, Mohan, & Hector, 2003).

The prime is immediately followed by a backward mask, which is represented by the last box in the figure. The backward mask is often the target, which is traditionally presented in uppercase. It is important that the prime and target be in different cases since presenting identical cases increases the chance that facilitation effects will be due simply to form-similarity. The target stays on the screen until either a response is made or a time limit expires.

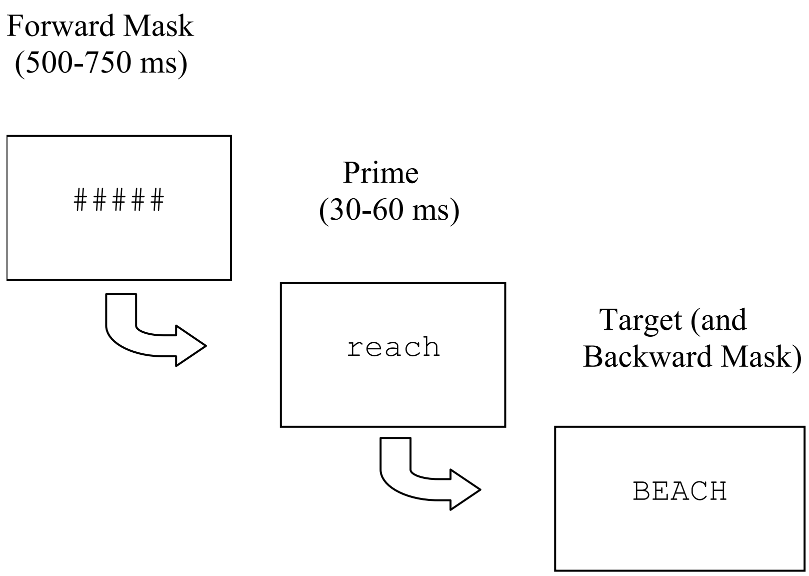

FIGURE 6. Computer-screen sequence for a generic masked-priming experiment (three-field paradigm).

Even though the participant is typically unaware of the masked prime, many experiments have shown that such primes can affect reaction times and error rates

(Kinoshita & Lupker, 2003). For more comprehensive reviews of the masked priming paradigm, see Forster (1998) or Forster et al. (2003).

This sequence of stimuli is the standard three-field paradigm (Forster, Mohan, & Hector, 2003). This is the same paradigm that will be used in my experiments. I will now describe the basic design of my experiments below, using as examples materials that could be given to English-reading adult participants. The Spanish version of the experiment is described in Chapter 4, where I present the materials and task for the Spanish monolingual adults. There was also another version of the English experiment for the child participants, which is described in Chapter 6.

3.2 General description of experiments

Table 1 summarizes the six conditions (three prime types by two response types) and the visual sequence of stimuli in my experiments. Recall that my experiments were all modifications of the letter-detection task used in Rey et al. (2000). But there is an important change in terminology. In Rey et al.'s (2000) experiments, double vowels were always vowel digraphs. So they refer to this condition as the digraph condition. My experiments will include Spanish materials, where there are double vowels, but no vowel digraphs. For this reason, I will now refer to the vowel digraph as a *double vowel*. Both English and Spanish, the languages used in my experiments, have double vowels. The double vowels in the English materials just happen to form vowel digraphs more often than not, whereas the double vowels in the Spanish materials do not form vowel digraphs.

The participants' responses were either YES (the search letter appears in the target word) or NO (the search letter does not appear in the target word). Participants indicated their answers by pressing buttons on a game controller. The right-index button was assigned as the YES response, and the left-index button the NO response. Both YES and NO responses were analyzed.

As in Rey et al.'s (2000) experiments, all the items in my experiments were words, and all items in any particular trial were matched on letter length. The relevant phonemic vowels for all target words were represented by single written vowels. The internal vowels for prime words were represented by either single or double written vowels. The response- and prime-type conditions are displayed in the leftmost columns in Table 1 below. They are explained in more detail below as I explain what the adult, English monolingual participants saw and did step by step.

All stimuli in the experiment were in the non-proportional, fixed-pitch font Courier New, size 14. This is standard practice in masked-priming experiments since proportional fonts will change the space occupied by each of the three stimuli (in a three-field paradigm).

TABLE 1. Design of Letter-Detection Experiment for Monolingual English Adults.

Condition		Sequence			
Response	Vowel prime type	Search letter 1,000 ms	Forward mask 1,000 ms	Prime 33 ms	Target
	Single			crest	
YES	Double			field	SPECK
	Control			block	
		E	##_#_##		
	Single			crest	
NO	Double			field	STAMP
	Control			block	

The first stimulus that participants saw was the search letter by itself (E in the example in Table 1). This was on the screen for 1,000 ms. During the experiment, the search letters were blocked (A, E, I, U, in that order), so this stimulus only served to remind the participant of the letter she was looking for, and to give her a location to fixate on.

Next, a forward mask of hashmarks (i.e., #####) replaced the letter. One of the hashmarks was colored red (e.g., E - ##_#_##),[25] and it appeared in the exact same position on the screen as the search letter had previously. This consistency in location, depicted in Figure 7 below, also extended to the relevant letters in the prime and target (described later). The participant was told to find the hashmark that was "colored differently," and to

[25] The underlined hashmark was red in the experiment, and not underlined.

keep her eye on it. The test administrator did not say “red hashmark” since I suspected that some participants might not have identified the color as red.[26] The other hashmarks were colored black.

```
  E        (1,000 ms)
  ↓
#####      (1,000 ms)
  ↓
field       (33 ms)
  ↓
SPECK
```

FIGURE 7. Location consistency of search letter, colored hashmark, relevant letter in prime, and relevant letter in target.

The reasoning behind including the colored hashmark is as follows. Rey et al. (2000) took measures to prevent positional effects by having the initial search letter appear where the relevant letter would appear in the target (the same letter for YES responses, and a different letter for NO responses). Positional effects are differences in reaction times due to the time that participants take to scan the word from various initial fixation points in order to find the search letter. I extended Rey et al.’s precaution against positional effects to masked priming. The participant could decide whether the answer was YES or NO simply by focusing her gaze on the spot that had been occupied, in turn, by

[26] In fact, some children identified the forward mask as orange or pink in the training phase.

the search letter, the colored hashmark, the relevant vowel letter in the prime, and the vowel letter in the target. Participants were told that the answer would always be in the spot where the colored hashmark had been.

The forward mask was also on the screen for 1,000 ms. There were two reasons for this slightly longer duration for the forward mask (most are presented for about 500-750 ms). One was the fact that the participant had to scan the mask for a particular color (as explained above). The other reason, based on the first, was the fact that children were going to do the experiment. I suspected they would need more time to scan the mask.

The next item to appear on the screen was the masked prime in lowercase letters. It remained on the screen for 33 ms. There were three different prime types, which, when divided by response type, formed the six conditions of the experiment. These are depicted in the next-to-last column on the right of Table 1. For single-vowel primes the search letter and the relevant letter in the prime were identical, and the relevant letter in the prime was bordered by two consonants (e.g., E → crest). For double-vowel primes, the search letter and the relevant letter in the prime were also identical, but the relevant letter in the prime was part of a vowel digraph in the English experiments (e.g., E → field). For control primes, the search letter and the relevant letter in the prime were different, and the relevant letter in the prime was bordered by consonants, as in the single-vowel primes (e.g., E → block). As noted above, the relevant vowel letter in all three prime types appeared where the colored hashmark had been.

Directly after the masked prime, the target appeared in uppercase (e.g., field → SPECK). This is depicted in the rightmost column of Table 1. The target remained on the screen for 2,000 ms. If the participant had not responded by that time, she saw a message indicating a timeout error, which was recorded.[27]

Note from Table 1 that in the materials for the NO responses, there were three different vowel letters in any given control-prime trial. That is, the search letter and the letters in the prime and target were all different (e.g., E → bl<u>o</u>ck → ST<u>A</u>MP). This differed from the control-prime trials for YES responses, where the search letter and the relevant letter in the target were identical (e.g., <u>E</u> → block → SP<u>E</u>CK). This extra constraint was necessary to maintain congruency relations between YES and NO responses. Response congruency between primes and targets is the behavior I measure in this dissertation to examine the respective roles of letters and graphemes in Spanish and English. But since congruency can be a somewhat confusing notion at first, I introduce it below without jargon. Afterwards, I will re-introduce the term, and use it from then on.

3.3 General experimental predictions

The dependent variables throughout my experiments are reaction times and error rates. In this section, I will lay out in non-technical terms how the monolingual Spanish and English participants might respond in this experiment to each prime type according each of the response types. I provide predictions for YES and NO responses, in that order.

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[27] The timeout period for children was longer. See Chapter 6.

Within each response type, I provide predictions for each prime type, starting with the control prime.

3.3.1 Control primes, YES responses

When the correct response to the target is YES, the suggestion to the participant from the control prime conflicts with the suggestion from the target. This conflict should increase reaction times, error rates, or both, making control primes inhibitory. To illustrate, if a participant seeks the letter E, and the target word is SPECK, a masked prime like *block* should hinder the participant's YES response. This is because *block* suggests to the participant that the correct response is NO (it contains the letter O in the relevant position instead of E). When the participant sees the target, she has to stifle this inclination to answer NO, and instead answer YES. The process of switching should increase reaction times and/or error rates. This prediction is the same in Spanish and English, on both the letter-as-percept and grapheme-as-percept models.

3.3.2 Single-vowel primes, YES responses

In contrast, the suggestion to the participant from the single-vowel prime agrees with the suggestion from the target when the answer is YES. This should decrease reaction times and/or error rates relative to the control primes, making the single-vowel primes relatively facilitative. When the participant is seeking the letter E, and a masked prime like *crest* precedes SPECK, the participant should respond relatively quickly. This is because the masked prime *crest* suggests to the participant, albeit very briefly, that the answer is YES. When she sees the target SPECK, which also requires a YES response, her inclination to respond YES is confirmed. There is no decision conflict.

Table 2 below outlines the relative advantages for the YES responses on the letter- vs. the grapheme-as-percept views. As can be seen here, the prediction of a relative single-vowel advantage is the same in Spanish and English, in both the letter- and grapheme-as-percept views. But the two views make different predictions in English and Spanish for double-vowel primes. This difference is covered next.

TABLE 2. Predicted Facilitation and Inhibition for Single- and Double-Vowel Primes for YES Responses in Spanish and English, according to Letter- and Grapheme-as-Percept Views.

		Different views	
Language	Vowel prime type	Letter as percept	Grapheme as percept
Spanish	Single	Facilitative	Facilitative
	Double	Facilitative	Facilitative
English	Single	Facilitative	Facilitative
	Double	Facilitative	Inhibitory

3.3.3 Double-vowel primes, YES responses

Table 2 shows that for double-vowel primes, the predictions from the letter- and grapheme-as-percept views are identical on the Spanish experiments, and different on the English experiments. I will cover the letter-as-percept view first. On this view, double-vowel primes should be just as facilitative, relative to control primes, as single-vowel primes. Further, this would be true in both English and Spanish. Since the letters are identical in both primes types in the two languages, and the claim is that English and Spanish readers perceive letters, there should be no difference in reaction times or error rates between the two prime types in either language.

Although the grapheme-as-percept view makes the same prediction as the letter-as-percept view in Spanish, it makes a different prediction in English. I will cover Spanish first. As explained at the beginning of Chapter 2, Spanish vowel letters always correspond to phonemes. So vowel letters and vowel graphemes are indistinguishable in Spanish. As a result, the predictions of the grapheme-as-percept view are indistinguishable from the letter-as-percept with respect to double-vowel primes, even if they make these predictions from different theoretical stances. For example, when the participant is looking for the letter I, and she is presented with a prime like SIERVO, she should perceive the I clearly since on the grapheme-as-percept view it is a solitary grapheme, and on the letter-as-percept view, it is a solitary letter. If either model is correct, then single- and double-vowel primes should be equally facilitative relative to control primes in this language.

But in English, double-vowel primes should be relatively inhibitory relative to single-vowel primes. On the grapheme-as-percept view, letters are nothing more, mentally, than structural components of graphemes. As a consequence, multi-letter graphemes can perceptually conceal, as it were, the identity of a letter (e.g., the letter E is concealed in the digraph IE in FIELD). According to Rey et al. (2000), extra abstract-grapheme units are activated in words with digraphs. These extra abstract-grapheme units (e.g., the IE, and E in FIELD, possibly I too) will compete with the single-letter abstract-grapheme unit activated by the target (e.g., the E in SPECK). This competition results in a time cost, which explained their results and Raslte and Coltheart's (1998) whammy effect. Single-vowel primes (e.g., the E in CREST) do not activate extra graphemes, just the one that is being sought. In English then, identifying the search letter in double-vowel primes should take longer than in a single-vowel prime. This would result in increased reaction times and/or error rates relative to single-vowel primes. The delays might even approach or perhaps equal those of the control primes.

In sum, the letter- and grapheme-as-percept views make identical predictions in Spanish, and different predictions in English. The predictions of these models for the NO responses are reversed in direction. Whatever was predicted as facilitative for YES responses will be inhibitory for NO responses, and vice-versa. This is explained next.

3.3.4 Control primes, NO responses

For the control primes when the correct answer is NO, the answer suggested by the prime is the same as required by the target. This is because the primes were selected so as not to match the search letter. If the search letter and the relevant letter in the prime had been the same (e.g., E → dwell → STAMP), the prime and target would have suggested different answers, nullifying any predicted differences between the control primes and the other prime types for NO responses. Instead, the search letter, the vowel letter in the prime, and the vowel letter in the target are all different. In this way, the prime suggests to the participant that the answer is NO, which is the same as the correct response to the target. When searching for E, for instance, the participant will see a prime like *block*, which suggests to her that the answer is NO. She will then see the target STAMP, for which the answer is also NO. This should result in decreased reaction times and/or error rates for the same reasons explained above in the YES responses.

3.3.5 Single-vowel primes, NO responses

When the correct response is NO, reaction times and/or error rates should increase for the single-vowel primes relative to the control primes. This makes the single-vowel primes relatively inhibitory. The single-vowel primes are relatively inhibitory because they suggest to the participant that the answer is YES, whereas the target suggests to her that it is NO. For instance, if a participant is searching for the letter E, and the target word is STAMP, which requires a NO response, then a masked prime like *crest* should hinder her response since it suggests that the answer is YES. When she sees the target STAMP, which requires a NO response, her inclination to respond YES has to be stifled. This conflict should increase reaction times and/or error rates relative to the control primes.

Table 3 below outlines the relative advantages for NO responses. The prediction of relative disadvantage for the single-vowel primes is the same in Spanish and English, in both the letter- and grapheme-as-percept models. But the prediction of relative advantage for the double-vowel primes is different on the two models. These differences are covered next.

TABLE 3. Predicted Facilitation and Inhibition for Single- and Double-Vowel Primes for NO Responses in Spanish and English, according to Letter- and Grapheme-as-Percept Views.

Language	Vowel prime type	Different views: Letter as percept	Grapheme as percept
Spanish	Single	Inhibitory	Inhibitory
	Double	Inhibitory	Inhibitory
English	Single	Inhibitory	Inhibitory
	Double	Inhibitory	Facilitative

3.3.6 Double-vowel primes, NO responses

For double-vowel primes in NO responses, the predictions from the letter- and grapheme-as-percept views are again identical on the Spanish experiments, but different on the English experiments.

On the letter-as-percept view, double-vowel primes should be equally inhibitory relative to control primes in both English and Spanish. On this model, since letters are the basic perceptual unit, there should be no perceptual difference between double vowels in Spanish and double vowels in English. That is, the double-vowel prime in Spanish will suggest the wrong answer to the participant, and the double-vowel prime in English will suggest the wrong answer. The conflict that arises between response inclination to the prime and target will be equally inhibitory in both languages.

As with YES responses, the grapheme-as-percept view makes the same prediction as the letter-as-percept view in Spanish, and a different prediction in English. In Spanish, there is no multi-letter vowel grapheme to conceal the presence of a vowel letter within it. Every vowel letter is, in effect, a vowel grapheme. Thus, grapheme-as-percept model would predict that Spanish double-vowel primes should be equally as inhibitory as single-vowel primes for NO responses. For the grapheme-as-percept view, then, the prediction for double vowels in Spanish is the same as in the letter-as-percept view, but for different theoretical reasons. For example, if the participant is looking for the letter I and is presented with the prime *siervo*, and then the target CONEJO, she will be slowed down since she can perceive the I in *siervo* quite clearly. On the grapheme-as-percept view, this is because I is always a solitary grapheme, and on the letter-as-percept view, this is because the I is a letter.

But on the grapheme-as-percept view, double-vowel primes in English should be relatively facilitative relative to single-vowel primes. Again, this differs from the letter-as-percept view, where there should be no difference. In the grapheme-as-percept view, letters are nothing more than components of graphemes. Since the multi-letter grapheme conceals the identity of the relevant letter in the prime (through abstract-grapheme competition in Rey et al.'s (2000) view), participants receive subconscious information from the prime indicating a NO answer. An alternative explanation is that they receive little or no information indicating that prime contains the letter they are looking for. In the former explanation, the suggestion from the prime concurs with the suggestion from the target, resulting in decreased reaction times and/or error rates relative to single-vowel primes. On the latter account, the suggestion from the double-vowel prime simply does not conflict with the suggestion from the target, resulting in less inhibition than from single-vowel primes.

3.3.7 Response congruency

As the effects expected in my experiments have now been explained in non-technical terms, it is now appropriate to describe them in more technical terms. The expected effects in this dissertation can be discussed in terms of response congruency. Response congruency refers to the compatibility of two decisions. In my experiments, it refers to the compatibility of the answer that the masked prime suggests to the participant, and what the target tells the participant the correct answer is. Thus, the first "decision" is subconscious, whereas the second decision is conscious. When the two stimuli suggest the same answer, they are response congruent, and they are likely to facilitate reaction times. When the two stimuli suggest conflicting answers they are response incongruent, and are likely to inhibit reaction times.

Response congruency in my experiments according to both the letter- and grapheme-as-percept views is represented in Table 4 below. In the left half of the table are the conditions. On the right are descriptions of the respective response congruencies. The two responses depicted in the response-sequence column refer to the decisions made on the prime and target. The response on the left is the predicted reaction to the prime, and the response on the right is the predicted reaction to the target. Where they agree, they are congruent and should facilitate reaction times. Where they disagree, they are incongruent and should inhibit reaction times. These descriptions match those just given in the Sections 3.3.1 through 3.3.6.

TABLE 4. Response Sequence, Congruency, and Expected Effects for English Experiment According to the Letter- and Grapheme-as-Percept Models.

Condition			
Response	Vowel prime type	Response sequence	Response congruency
YES	Single E→cr<u>e</u>st→SP<u>E</u>CK	YES→YES	Congruent
	Double E→fi<u>e</u>ld→SP<u>E</u>CK	YES→YES[a] NO→YES[b]	Congruent[a] Incongruent[b]
	Control E→bl<u>o</u>ck→SP<u>E</u>CK	NO→YES	Incongruent
NO	Single E→cr<u>e</u>st→ST<u>A</u>MP	YES→NO	Incongruent
	Double E→fi<u>e</u>ld→ST<u>A</u>MP	YES→NO[a] NO→NO[b]	Incongruent[a] Congruent[b]
	Control E→bl<u>o</u>ck→ST<u>A</u>MP	NO→NO	Congruent

Note. Unless otherwise noted, congruency is presented according to both the letter- and grapheme-as-percept models.
[a] According to the letter-as-percept model only.
[b] According to the grapheme-as-percept model only.

3.4 Order of presentation

The current chapter has been dedicated to clarifying how letter-detection experiments with masked priming in Spanish and English will help determine whether graphemes are perceptual reading units. The results of these experiments with Spanish and English monolingual adults are presented in the next chapter. They are presented first because they provide the closest link to the perceptual issues brought up in Chapter 2. These two groups also provide the closest parallel to the English and French groups tested by Rey et al. (2000). The experiments with the bilingual adults and the children are presented in Chapters 5 and 6, respectively.

CHAPTER 4 STUDY OF ADULT MONOLINGUALS

I will start with the Spanish monolingual adults doing the main task in Spanish with 33-ms primes. If either the letter- or grapheme-as-percept views is correct, then there should be no difference in facilitation between the single- and double-vowel primes in Spanish.

After reporting on the tests with the Spanish monolingual adults, I present the results of the English monolingual adults doing the task in English. I then cover the follow-up experiments in English that were given to other, native English participants. All but one of the follow-up experiments involved increasing the prime duration in order to exclude response-bias effects and phonological effects. The one that did not involve increasing the prime duration was not a priming experiment to begin with, but rather a modified replication of Rey et al (2000).

4.1 Experiment 1: Spanish monolingual adults with 33-ms primes

Recall from Chapter 2 that Spanish has double vowels but lacks vowel digraphs. That is, every vowel refers to either a single phonemic vowel or a single, phonemic semi-glide, even when written vowels are adjacent. This means that Spanish monolingual adults should show equal priming for single- and double-vowel primes. For example, the Spanish word SIENTO contains adjacent vowels, but the first vowel clearly corresponds to a glide (/sʲento/). Thus, the masked prime *siento* should facilitate detection of the letter

E in the target PR<u>E</u>NSA just as much as the masked prime *fl<u>e</u>cha*. Both the letter- and grapheme-as-percept views make this prediction.[28]

4.1.1 Participants

It is difficult to find truly monolingual Spanish participants in southern Arizona. Further, I also considered the probability that such participants, even if they could be recruited just over the border with Mexico, would be fairly unfamiliar with computer technology. If so, my computer-based experiments might have stressed these participants to some degree, making their performance less comparable to that of the other groups in the study.

For these reasons, I tested adults in Rosario, Argentina. It was easy to find participants there who were familiar with computer technology. But it was still difficult to find truly monolingual Spanish readers; most had studied some foreign language. Ultimately, I tested 21 participants who either had not studied English, or had not done so within the previous 3-4 years. All were working or studying in Argentina. If they knew a foreign language, they used it very infrequently. They all had normal or corrected vision.

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[28] Readers familiar with the DRC probably have noticed that I am making claims about how polysyllabic words would be recognized, and that the nonlexical route of the DRC is not yet designed to handle polysyllabic words (Coltheart et al., 2001, pp. 250-251). Keep in mind, however, that I am only using the DRC as a particularly useful example of a letter-as-percept model, and am making claims only about letter vs. grapheme perception (e.g., the abstract unit stage in the DRC). Nonetheless, the model becomes useful again later when I invoke phonological effects in order to explain the data. Any reference to the DRC in relation to the results in my study (with polysyllabic words) should be considered speculation on my part since the developers of the DRC have avoided issues of polysyllabicity.

4.1.2 Procedures

This section reviews the characteristics of the items used in the Spanish experiment. First, targets are covered, then primes. The section ends with the number of trials in each of the six conditions, the items that were ultimately included in the analysis, and the role of counterbalancing in the experiment. After that, the task is explained.

4.1.2.1 Materials

Item statistics are summarized in Table 5 for Spanish targets, and in Table 6 for Spanish primes. In Table 5, the targets are divided into low- and high frequencies, but the primes are all low frequency, so no such division appears in Table 6. The complete set of items by condition for the Spanish experiment can be found in Appendix A (p. 241) for the low-frequency targets, and in Appendix B (p. 242) for the high-frequency targets.

First, I will discuss targets. Among the 96 targets, there were 72 six-letter words and 24 seven-letter words. Also, there were 40 disyllabic (e.g., PASTEL), 54 tri-syllabic (e.g., NULIDAD), and 2 quadri-syllabic targets (e.g., ASIDERO). The overall mean number of syllables for targets was 2.59 (SD = 0.51). In the YES responses, this was 2.50 (SD = 0.51); in the NO responses, this was 2.69 (SD = 0.51). Primes and targets were matched for number of letters, but not number of syllables.[29] None of the targets in the Spanish experiment had any diacritics.

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[29] The average number of syllables in the Spanish items is higher than that in the English items (see Section 4.2.2.1 below, pp. 120-124). The higher number of syllables and letters in the Spanish items reflects the fact that Spanish syllables have fewer legal codas

The frequencies of the Spanish words were determined using Alameda and Cuetos (1995).[30] Of all the targets selected, 25% were high frequency. Their mean frequency was 105.54 per two million (SD = 27.65). The mean frequency for the low-frequency targets was 6.01 per two million (SD = 4.34). In the YES responses, the mean was 101.33 per two million (SD = 29.56) for the high-frequency targets, and 5.44 per two million (SD = 3.65) for the low-frequency targets. In the NO responses, the mean was 107 per two million (SD = 26.07) for the high-frequency targets, and 6.58 per two million (SD = 4.91) for the low-frequency targets.

TABLE 5. Item Statistics (Counts and Mean Frequencies) for Spanish Targets.

		Syllables			Letters		
Frequency	n	Two	Three	Four	Six	Seven	Mean frequency
Low	72	29	43	0	56	16	6.01 (4.34)
High	24	11	11	2	16	8	105.54 (27.65)
Total	96	40	54	2	72	24	30.90 (45.56)

Note. SD in parentheses.

Next, I will discuss primes. As noted above, items varied from two to four syllables in length. The average number of syllables for primes was 2.58 syllables (SD =

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than the English or French items used in Rey et al. (2000). Matching the Spanish items to the English or French items in terms of number of syllables and number of letters would have reduced the item pool to too few candidates.

[30] This corpus is based on two million words as opposed to the one million in the Kučera and Francis (1967) corpus for English.

0.53). In the YES responses, the mean was 2.48 (SD = 0.54). In the NO responses, the mean was 2.69 (SD = 0.51). For the single-vowel primes, the average number was 2.68 (SD = 0.51). For the double-vowel primes, it was 2.40 (SD = 0.53). And for the control primes, it was 2.68 (SD = 0.51).

Again, all primes were low frequency. Their mean frequency was 6.66 per two million (SD = 4.99). In the YES responses, the mean frequency was 6.83 per two million (SD = 4.81); in the NO responses, it was 6.49 per two million (SD = 5.18). The mean frequency for single-vowel primes was 6.68 (SD = 5.57). For double-vowel primes, it was 6.95 (SD = 5.12). And for control primes it was 6.36 (SD = 4.21).

Sometimes the search letter appeared as the left member of the vowel pair in the double-vowel primes (e.g., E → neutro → MEZCLA) and sometimes as the right member (e.g., E → huelga → INEPTO). Overall, it appeared on the left-hand side in 62.5% of the cases, and on the right-hand side in 37.5% of the cases. In the YES responses, these percentages are 67% and 33%, respectively. And in the NO responses, they are 58% and 42%.

TABLE 6. Item Statistics (Counts and Mean Frequencies) for Spanish Primes.

Vowel	Syllables: Two	Syllables: Three	Syllables: Four	Position of search letter in double vowel: Left	Position of search letter in double vowel: Right	Mean frequency
Single (n=96)	33	61	2			6.68 (5.57)
Double (n=96)	60	34	2	60	36	6.95 (5.12)
Control (n=96)	33	61	2			6.36 (4.21)
Total	126	156	6	60	36	6.66 (4.99)

Note. SD in parentheses.

Now I will discuss the allocation of items to the six conditions of the experiment, which is summarized in Table 7 below. There were 48 target words for each of the YES and NO responses (16 single-, 16 double-, and 16 control-primes for each of the 48 YES items and 48 NO items). These are summed by rows in the table. There were 24 items total for every search letter (12 YES and 12 NO for A, E, I, and U). These are summed in columns. Counting across the YES and NO responses, there were 8 single-vowel primes (4 YES, 4 NO), 8 double-vowel primes (4 YES, 4 NO), and 8 control primes (4 YES, 4 NO) for each search letter.

TABLE 7. Allocation of Items by Condition and Search Letter in Spanish Experiments.

Condition		Search letter				
Response	Vowel prime type	A	E	I	U	Total
YES	Single	4	4	4	4	16
	Double	4	4	4	4	16
	Control	4	4	4	4	16
NO	Single	4	4	4	4	16
	Double	4	4	4	4	16
	Control	4	4	4	4	16
	Total	24	24	24	24	**96**

When broken down by frequency, there were 12 primes in each condition for low-frequency targets, and 4 primes in each condition for high-frequency targets. This breakdown can be seen in Table 8 below.

Again, targets were both high and low frequency, while primes were all low frequency. Unfortunately, too few high-frequency targets were included to draw any conclusions about frequency. Therefore, I will not report results with the high-frequency items. In fact, this is true for the experiments throughout this dissertation.[31] This means that the analysis will include 72 items total. There were 36 items for each of the YES and NO responses. Each response type was, in turn, comprised of three groups of 12 items, corresponding to the three prime types. This is represented in the right-hand column of Table 8.

[31] The experiment for the children never included any low frequency items. See Chapter 6.

TABLE 8. Number of High- vs. Low-Frequency Items by Condition in Adult Experiments.

Condition		Frequency	
Response	Prime type	High[a]	Low
YES	Single	4	12
	Double	4	12
	Control	4	12
NO	Single	4	12
	Double	4	12
	Control	4	12
Total		16	72

[a]Not included in analyses

Counterbalancing served to cancel out potential confounding effects due to characteristics of the target words. It is possible to inadvertently choose target items that turn out to differ in some way other than intended. Experimental designs where such items are not counterbalanced covertly inflate the chance of committing a Type I error. To avoid this in my experiments, each prime type preceded each individual target via three different files, which were in turn randomly assigned to participants in equal numbers. This manipulation helps cancel out any effect that unusual items might otherwise confer on one condition in a non-counterbalanced design.

4.1.2.2 Task

The six conditions of the experiment along with what the participants saw was presented in the previous chapter. However, it may be useful to the reader to see a reproduction of Table 1 (p. 76) in Chapter 3, but with Spanish example stimuli. This is done in Table 9 below.

TABLE 9. Design of Letter-Detection Experiment for Monolingual Spanish Adults.

Condition		Sequence			
Response	Vowel prime type	Search letter 1,000 ms	Forward mask 1,000 ms	Prime 33 ms	Target
	Single			virrey	
YES	Double			siervo	HINCAR
	Control			lustre	
		I	######		
	Single			virrey	
NO	Double			siervo	CONEJO
	Control			lustre	

The participants performed the experiment on laptop computers using DMDX software (Forster & Forster, 2003). DMDX displays items and records reaction times to and errors on those items. Participants were randomly assigned to one of the three counterbalanced files. The responses to the letter-detection task were recorded through a game controller connected to the laptop.[32] Participants pressed the right index button to indicate that the letter was present in the word and the left index button to indicate that it was not. They did this as quickly and as accurately as possible.

The Spanish monolingual participants received instructions about equipment and procedures orally in Spanish. Before the experiment began, they read the same instructions in Spanish on the computer screen. These written instructions are given in Appendix C (p. 243) along with their English counterparts. A practice set of 12 trials (using the search letter A) followed the written instructions. The letter A was chosen to help ensure that participants would begin the experimental items already predisposed to look for the appropriate search letter. The practice items mirrored the conditions in the actual test. In this way, data were recorded only after participants had adjusted to the task. After the practice items, participants started on the 96 experimental items.

The experimental items were presented in blocks ordered alphabetically by search letter in order to reduce the probability that participants would forget which letter they were searching for on any particular trial. Thus, participants first responded to whether or not the search-letter A appeared in targets. Participants then responded to the search letters E, I, and U in that order. The experiment ended when the participants finished the U block. Within each search-letter block, DMDX grouped the 24 trials into four sub-blocks of six trials each. Each sub-block contained a representative trial from each of the six

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[32] Two laptop computers were used for the Spanish monolingual adults. One was a Toshiba Satellite A45-S121 and the other a Gateway 400SD4. Both were running DMDX on Windows XP. The input device for both was a *Saitek P880 Pad USB* game controller.

conditions in the experiment (i.e., single-vowel, double-vowel, and control primes, both YES and NO responses; see left-hand columns in Table 9). DMDX randomized the presentation of trials at both levels. That is, for each letter, the four sub-blocks of six trials were presented in random order; and, within each sub-block, the six trials were presented in random order.

At the end of the experiment, I debriefed the participants on the nature of the study. They were then given a small compensation fee. Finally, I thanked them for having participated.

4.1.3 Results

The data from participants with error rates above 20% were not included in the analyses (but in fact, no participant in this group had such a high error rate). Also, since the task is an unusually easy one, it was reasonable to assume that any reaction times shorter than 200 ms or longer than one second on any particular trial were the result of random error on the part of the participant (e.g., distraction). Therefore, all reaction times below 200 ms or above 1,000 ms were deleted on individual trials for the remaining participants. It can also be assumed that reaction times outside any given participant's normal response range can be attributed to random error, which justifies trimming the means. The normal response range is often defined as 2 SD on either side of that participant's mean. For this reason, means and standard deviations were calculated for each participant, and reaction times lying above or below two standard deviations from the participant's own mean were trimmed to ± 2SD from that mean, respectively. This is a standard means-trimming procedure used in reaction-time studies. The resulting mean reaction times across all Spanish monolingual adults can be seen in Figure 8. Mean errors, reaction times, facilitation, and benefit can be seen in Table 10.

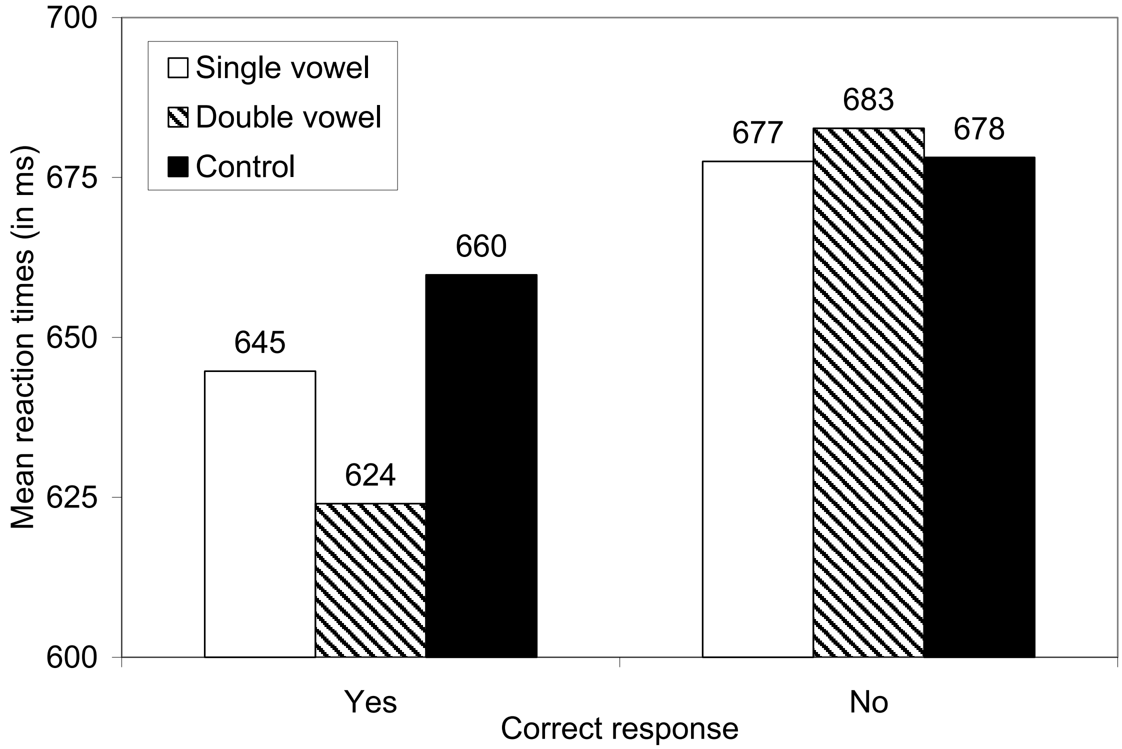

FIGURE 8. Mean reaction times (in ms) for Spanish monolingual adults with 33-ms primes.

For each experiment, there were four main comparisons. In both YES and NO responses, the mean reaction times for the single- and double-vowel primes were subtracted from those of the control primes. These comparisons are all classified in Table 10 below (and most other results tables in this dissertation) under the label "Facilitation." When the value is positive, it is referred to as *facilitation*. When it is negative, it is referred to as *inhibition*. It is possible to find facilitation and inhibition for both single- and double-vowel primes (i.e., single-vowel facilitation, single-vowel inhibition, double-vowel facilitation, double-vowel inhibition). I do not do these comparisons with error rates since it would be difficult to interpret such figures.

There are two more comparisons. In these comparisons (one each for the YES and NO responses), the mean reaction times of the single-vowel primes are subtracted from those of the double-vowel primes. These comparisons are classified in Table 10 (as in most other results tables) under the label "Benefit." When the benefit is positive, it is referred to as a *benefit*. When it is negative, it is referred to as a *detriment*. Note that by virtue of subtracting the single-vowel mean from the double-vowel mean, any benefit (or detriment) corresponds to the single-vowel prime. Thus, benefits and detriments are referred to in text as *single-vowel benefits* and *single-vowel detriments*. Importantly, recall that neither the letter- nor grapheme-as-percept views predict single-vowel benefits or detriments in Spanish. But the grapheme-as-percept view does predict them in English. Lastly, these comparisons are not done with error rates since they would be difficult to interpret.

In the analysis of reaction times, a 2x3 factorial ANOVA (Response x Prime Type) showed a main effect for response. This was significant both by participant, $F_1(1,18) = 14.29$, $p < .002$, and by item, $F_2(1,30) = 24.59$, $p < .0001$. There was also a main effect for prime type, which was significant both by participant and by item, $F_1(2,36) = 4.00$, $p < .03$, $F_2(2,60) = 3.39$, $p < .05$. Finally, there was a significant interaction between response and prime type. This was Significant by participant, but marginal in the analysis by item, $F_1(2,36) = 4.90$, $p < .02$, $F_2(2,60) = 2.91$, $p < .07$.

Planned comparisons for the means showed significant differences for the YES responses only. The 36-ms facilitation for double-vowel primes was significant by item and by participant. The 15-ms facilitation for the single-vowel primes was marginal in the analysis by participant, and not Significant by item. The 21-ms single-vowel detriment was not significant.

In the analysis of error rates, a 2x3 factorial ANOVA (Response x Prime Type) showed no main effects or interactions (all *F*'s < 1).

TABLE 10. Mean Error Rates, Reaction Times (RT), Facilitation, and Benefit for Spanish Monolingual Adults (N=21) with 33-ms Primes as a Function of Response and Prime Type.

	Dependent measures					
Response and vowel prime type	Error rate (%)		RT (ms)		Facilitation (ms)	Benefit (ms)
YES						
Single	6.3	(6.9)	645	(99)	15	-21
I→*virrey*→*HINCAR*						
Double	4.0	(5.0)	624	(98)	36*	
I→*siervo*→*HINCAR*						
Control	5.2	(6.2)	660	(92)		
I→*lustre*→*HINCAR*						
NO						
Single	5.3	(5.6)	677	(95)	1	6
I→*virrey*→*CONEJO*						
Double	5.3	(6.8)	683	(103)	-5	
I→*siervo*→*CONEJO*						
Control	5.7	(6.8)	678	(96)		
I→*lustre*→*CONEJO*						

Note. Facilitation = [Control]-[Single] and [Control]-[Double]. Benefit = [Double]-[Single]. SD in parentheses.
* Significant by participant and by item

4.1.4 Discussion

Before I can draw conclusions from this experiment regarding the nature of single- and double-vowels, I need to show that the masked-priming experiment worked:

that participants used information from the primes to make decisions on the targets. This was indeed the case. The monolingual Spanish participants showed facilitation in the YES responses. They were significantly faster to respond after double-vowel congruent primes than after incongruent primes (i.e., controls) in the YES responses. That this was not true for the single-vowel primes in YES responses, or at all in the NO responses will be explained shortly. The facilitation in the expected direction is evidence that the experiment worked: Participants used information from the primes to respond to the targets.

I can now turn to the predictions regarding how monolingual Spanish participants should respond with single- vs. double-vowel primes. Recall from Chapter 3 (Section 3.3.) that the letter- and grapheme-as-percept models both predict that, in Spanish, the single- and double-vowel primes should elicit the same mean reaction times and/or error rates relative to control primes. For the YES responses, both single- and double-vowel primes should be facilitative, or shorter relative to the control primes. For the NO responses, they should be inhibitory, or longer relative to the control primes. There should be no differences between the single- and double-vowel prime types themselves.

The monolingual Spanish participants responded faster to YES targets when the prime contained a double vowel than when the prime contained a single vowel. This "isolated double-vowel" (IDV) facilitation was unexpected. Neither the letter- nor the grapheme-as-percept views would predict such an outcome. On either view, for YES responses, there should have been equal facilitation for the single- and double-vowel primes in Spanish.

But there are some possible explanations for the IDV facilitation if one questions the assumption that the effects found in this letter-detection task were confined to the abstract-letter or -grapheme stage. In contrast to Rey et al.'s (2000) experiments, the masked priming experiments in this dissertation help limit the explanation of any effects to subconscious processing. But even masked priming does not necessarily confine explanations to particular stages in automatic processing. And there is little reason to believe that it did so in this experiment. If letter detection does not take place at an abstract-unit stage (i.e., abstract letters or abstract graphemes), then the effects of this masked-priming experiment must be attributed to some automatic stage within the normal reading process. Recent claims regarding sublexical representation in Spanish may provide a clue as to how this might occur.

To make this explanation clear, first I must provide more details about Spanish double vowels. In written Spanish, the letters I and U, when adjacent to A, E or O, represent diphthongs, and the sound represented by the I or U is a glide.[33] When adjacent, the first represents a glide.[34] By definition, diphthongs are within syllables.[35] Examples of

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[33] In some dialects of Spanish, some vowel pairs including a high vowel are perceived as separate syllables. This is fairly rare however, and only occurs in some words in that dialect. See Hualde and Prieto (2002) for an investigation of this phenomenon.
[34] Except in the case of GUI, GUE, QUI, and QUE for reasons discussed in Section 2.2.

such combinations are CUENTA /k^{w}en.ta/, and SIESTA /s^{j}es.ta/.[36] In contrast, when the vowel pair consists of any combination of A, E, and O, a *hiatus* is represented. A hiatus refers to two adjacent vowels that belong to separate syllables. Examples of this in Spanish are CAOBA /ka.o.ba/ and FEO /fe.o/.[37]

This aspect of the materials was not considered when the experimental items in Spanish were chosen since in both cases, each letter represents a phoneme. The result was that the double-vowel primes contained, on average, fewer syllables than both single-letter primes and targets. This is because most of the double-vowel primes contained glides (I or U in this case). Table 5 in Section 4.1.2.1 above contains information for both high- and low-frequency targets. But only the low-frequency targets were analyzed. I reproduce Table 5 as Table 11 below. But I restrict the statistics here to primes for low-frequency YES responses only, along with their respective targets. It is easy to see the difference between the items in the double-vowel prime type and the other items. Relative to the other three item types, the double-vowel primes had almost twice as many two-syllable items and less than half as many three-syllable items. It is also clear that for

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[35] There is some debate as to whether the glide, when it precedes the main vowel, is part of the onset or the nucleus. But this debate has little relevance to this dissertation. See Harris (1983) or Núñez Cedeño and Morales-Front (1999) for more information.
[36] Accent marks can signify exceptions to this rule (e.g., MÍA, REÚNE, CAÍDA, BAÚL, VEINTIÚN, RUÍZ), but no item contained accent marks in this experiment.
[37] Some speakers of the language even concatenate certain [-high] vowel combinations into one syllable. For instance, one might pronounce TEATRO not as /te.a.tro/, but as /tea.tro/, or even /t^{j}atro/. This process is called *synaloepha*, and occurs often in rapid speech in Spanish (Azevedo, 2005; Cressey, 1978; Núñez Cedeño & Morales-Front, 1999).

all but the double-vowel item types, the number of two- vs. three-syllable items is relatively balanced, with slightly more three- than two-syllable items. In contrast, the double-vowel item type contains four times as many two- as three-syllable items.

TABLE 11. Number of Syllables by Item Type for all Low-Frequency Items in Experiment with Monolingual Spanish Adults.

	Syllables			
Item	Two	Three	Four	Mean no. of syllables
Single-vowel primes	16	19	1	2.58 (0.55)
Double-vowel primes	28	7	1	2.25 (0.50)
Control primes	15	20	1	2.61 (0.55)
Targets	18	18	0	2.50 (0.51)

Note. SD in parentheses.

With these differences in the materials in mind, it is now appropriate to cover some recent theorizing about sublexical representation in Spanish. Combined, these factors may provide a clue as to why the Spanish monolingual adults were faster with the double-vowel primes.

Some researchers theorize that the syllable may play a major role in Spanish visual word recognition (e.g., Álvarez, Carreiras, & de Vega, 2000; Álvarez, de Vega, & Carreiras, 1998; Carreiras, Alvarez, & de Vega, 1993; Carreiras & Perea, 2002; Dominguez, de Vega, & Cuetos, 1997). This conclusion revolves around a fairly consistent effect in which the positional frequency of the syllable[38] seems to have an inhibitory effect on visual word recognition. For instance, using a masked priming paradigm in lexical decision, Carreiras and Perea (2002) found that responses to word targets were slower than controls when the prime was a syllabic neighbor of high frequency (a word of higher frequency with the same first syllable). When the prime was a syllabic neighbor of low frequency, there was no difference in reaction times relative to controls. When nonwords sharing the first syllable were used as primes, reaction times were facilitated.

Carreiras and Perea (2002) appealed to a model in which words are accessed through activation of syllabic units, which in turn activate candidates in the lexicon. The presentation of a relatively higher frequency prime with an identical initial syllable activated a number of candidates above and beyond what the target word itself would activate. This created more competition, resulting in inhibited responses. The nonwords could not, ultimately, activate enough lexical entries to foster inhibition, but they could activate enough sublexical information to facilitate responses.

The idea that syllables are the basic unit of word recognition also makes sense in light of Spanish orthography. As noted at the beginning of Chapter 2 (Section 2.2), there are between three and five multi-letter graphemes in Spanish (i.e., indisputably CH, LL, and RR; probably also GU and QU). This is not very many relative to the number of cases

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[38] Positional syllable frequency is the frequency of a particular syllable in a particular syllable slot across words.

in which letters and graphemes are isomorphic. This means that a process converting each letter into a grapheme in Spanish would result in very little net gain of information. Using letter combinations to activate syllables, however, would net a great deal of information. This also makes one wonder whether it would make any sense to extend to Spanish the notion that letters are converted to graphemes along the nonlexical route.[39] It might be more productive in Spanish to convert letter groups into syllables.

It may seem strange that Spanish readers would make decisions about letters from syllables (written syllables, to be exact). But this proposal is no stranger than the idea that native English readers make decisions from graphemes (see my summary of the digraph effect found in Rey et al, 2000). Both explanations are based on the activation of phonological representations somewhere along the nonlexical route, or prior to it.

But it seems that the syllable and abstract syllable structure are important word-recognition unit in Spanish. Abstract syllable structure in the literature that follows refers to the sequence of consonants and vowels in a syllable. For instance, a simple open vowel would be CV (consonant-vowel), and a simple closed vowel would be CVC (consonant-vowel-consonant). Using two different experimental paradigms, Costa and Sebastian-Gallés (1998) found evidence that abstract syllable structure affected reaction times even when the phonological segments themselves differed. In their first experiment, they tested whether word distracters presented 150 ms after pictures would interfere with the

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[39] I am not aware of any attempt to describe what the nonlexical route in the DRC would look like in Spanish. I am speculating here.

naming of those pictures (the picture-word interference task). The words were varied in terms of whether they matched the phonemes or the abstract syllable structure of the first syllable in the name of the picture. For example, a picture of a tail /ko.la/ (CV.CV) would be followed 150 ms later by the following words: a) COTO, whose first syllable matches the picture name both segmentally /ko/ and in terms of abstract syllable structure (CV); b) COSTA, whose first syllable contains a segmental match /ko/ but does not share syllable structure (CVC); c) NIDO, whose first syllable matches only on abstract syllable structure (CV); and d) NINFA, whose first syllable does not match the first syllable in the name of the picture.

Costa and Sebastian-Gallés (1998) found that phonemically matched words (/ko.la/ - COTO/COSTA) facilitated picture naming more than phonemically mismatched words (/ko.la/ - NIDO/NINFA). More importantly, they found evidence that words matched to the abstract syllabic structure of the name of the picture (e.g., /ko.la/ - NIDO) facilitated reaction times more than words mismatched on initially syllable structure (e.g., /ko.la/ - NINFA). They also found this with nonwords.

In another experiment, using a novel habituation paradigm, Costa and Sebastian-Gallés (1998) primed picture targets (e.g., a picture of a monkey, the pronunciation of which in Spanish is /mo.no/ CV.CV), with lists of words whose initial syllables either matched on abstract syllable structure (e.g., CV: pa.lo, ci.rro, pe.se, ga.la, ba.rre, pu.lo) or did not match (CVC: pes.te, gal.go, bar.bo, pul.ga, pal.mo, cir.co). They also included lists that were equally divided between matching and mismatching abstract, initial syllable structure (the neutral condition), and picture targets with initial CVC structure. Participants had to name all members of the list as quickly as possible, after which they saw the target and also named it as quickly as possible. When lists and pictures contained the same abstract syllable structure, pictures were named faster. Costa and Sebastian-Gallés concluded that abstract syllable structure facilitates word recognition. They also found no significant differences between mean reaction times to targets preceded by mismatching lists and targets preceded by neutral lists. They concluded that abstract syllabic structure is purely facilitative. That is, matching abstract syllabic structure can facilitate word recognition, but mismatching abstract syllabic structure cannot inhibit word recognition.

Combined with the syllabic implications of double- vs. single-vowels in Spanish, a syllable-based activation account could explain the surprising IDV facilitation effect in one of several ways. I cover four possibilities below, but only one seems plausible.

One possible explanation for the IDV facilitation effect in Spanish is that perhaps single-vowel primes and targets shared more syllables than the double-vowel primes and targets. If increased similarity existed between the two item types, then the single-vowel primes would have activated many of the same syllables as the targets did. Ultimately, this would lead to overlapping activation of syllables and increased competition. The increase in competition would increase the time necessary to resolve the form of the syllable, and by extension, the form of the letter.

But this particular explanation using syllable activation could not be true. All trials were controlled so that syllables did not overlap between primes and targets. Primes and targets would seldom have activated the same syllables. When they did, they did so only in different locations in the word.

A second way to explain the IDV facilitation effect is by arguing that, although each syllable activates its own set of lexical candidates in Spanish, only candidates of equal syllable length compete with each other for resolution. If this is the case, then one can appeal to a probable characteristic of the trials to explain the effect. As shown in Table 11 (p. 109), the distribution of two-syllable and three-syllable items was more similar for single-vowel primes and targets than for double-vowel primes and targets. The probability must also have been higher, therefore, that the number of syllables between prime and target matched more often in trials with single-vowel primes than in trials with double-vowel primes. The likelihood would then also have been higher that single-vowel primes and targets activated competing sets of lexical candidates that matched in total number of syllables, leading to inhibition. Conversely, the probability must have been lower that double-vowel primes and targets did so, leading to less inhibition (observed as facilitation).

Interestingly, however, the number of syllables between prime and target did not match more often in trials with single-vowel primes than in trials with double-vowel primes. They matched perfectly for YES responses, where the effect occurred (21 matches and 15 mismatches for both single- and double-vowel primes). This balance between the trial types for YES responses was unintentional, but, nonetheless, serves to rule out this particular explanation.

The third possible explanation is that the shorter reaction times for the double-vowel primes are due solely to the fewer average number of syllables for those primes. The larger average number of syllables among the single-vowel primes activated more lexical candidates on average, which in turn leads to more competition, on average. This account presupposes that the entire syllable structure for the word is activated in a very short period of time. This is possible, but seems difficult to imagine given the fact that the task involves letter identification only.

The last, and in my view the most plausible account of the IDV facilitation effect in Spanish, posits that syllables and abstract syllable structure are mandatory units of word recognition. On this story, participants would have generated syllables and abstract syllable structure after perceiving the prime. The abstract syllable structure activated by single-vowel primes would have matched the abstract syllable structure activated subsequently by the target. This is either because single-vowel primes and targets both have consonants surrounding the target vowel (CVC), or because single-vowel primes (and control-vowel primes) tended to share more monophthongal syllables with targets, or both. This congruent abstract syllable structure would help hold the syllables activated by the single-vowel prime in a memory buffer. Thus, the candidate syllables activated by the prime would either compete with or reinforce the candidate syllables activated by the target, leading to inhibition.

In contrast, the abstract syllable structure activated by the double-vowel primes (e.g., CVV or VVC) would be incongruent with that of the target. This incongruent abstract syllable structure would not help syllables activated by the double-vowel prime persist in a memory buffer. The participant could make a relatively unimpeded decision on the target after a double-vowel prime, relative to after a single- or control-vowel prime.

There is a way to test these last two activation-competition explanations against each other. To do this, one would choose items in which the relevant vowel was embedded in a closed syllable for all single-vowel primes, but in an open syllable for all double-vowel primes. One would also include combinations of A, E, O, Í and Ú which create hiatuses (accents over the I and U are critical to make this happen). This manipulation would help match syllable and letter length across all items. If IDV facilitation still occurred with prime sets matched on letter and syllable length, it would be possible to rule out the explanation that relies solely on average number of syllables. Only the explanation that relies on abstract syllable structure could explain such data.

Note that among all these explanations so far, there is no way to determine whether the IDV facilitation effect was due to syllable competition or subsequent lexical-candidate competition. But it might be possible to tease apart these constructs experimentally. To do this, one would repeat the experiment with nonword targets. If IDV facilitation persisted with word targets and extended to nonword targets, then it could be attributed to syllable activation with more confidence. But if the effect occurred with words but not nonwords, then the activation of lexical candidates would have played a role.

Another way to do this would be to include high- and low-frequency primes in the experiment.[40] If it turned out that there was also a frequency effect, one could conclude with more confidence that the effect had to do with lexical activation and competition. If it turned out there was no effect of prime frequency, then one could conclude that participants were making decisions based on syllable competition, quite probably along the nonlexical route of a dual-route model. This issue will be addressed again at the end of this chapter in the summary (Section 4.5), when the results of the experiments in English have been presented.

In any case, the experimental modifications just mentioned will have to be reserved for future studies. As noted at the beginning of this chapter, Spanish monolingual adults who are appropriate candidates to perform forced-choice computer-based tasks are not easy to find in southern Arizona, or the United States for that matter.

The absence of any effect in the NO responses is difficult to explain from the theoretical account presented above. However, these participants were the first to be tested. After I ran many of these participants, I realized that I might not have emphasized sufficiently an important characteristic of the task. By definition, in the NO responses, the search letter is absent from the fixation point in the target. However, if not warned

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[40] As noted above, frequency in my masked-priming experiments was manipulated among targets, not primes. So whether there had been enough of them to include in the analysis would have been of no help here.

otherwise, participants might be inclined to search elsewhere in the word for the search letter. Information picked up elsewhere in the word could have interfered with their responses. Targets in NO responses were carefully controlled not to contain the search letter elsewhere in the word, but this probably did not matter if participants felt that they might find it elsewhere. This would be particularly tempting in Spanish, where there are more vowels dispersed throughout any given letter string than in English. The fact that participants did not need to look elsewhere in the word was mentioned in the oral instructions in these experiments, but not emphasized. In later experiments, I was careful to emphasize this point, and the trends and significant effects in NO responses reappeared, as the reader will see.

It still remains to be seen how English monolingual adults will do on the English version of the letter-detection task. Given the results in the Spanish experiment, it is now necessary to leave open that possibility that English monolingual adults may show an IDV facilitation effect. If it does surface in English, I would probably have to conclude that the effect is due to something about the task itself. If it does not, then the results of the experiment will more easily be attributed to language-specific processing.

4.2 Experiment 2A: English monolingual adults with 33-ms primes

The results in Spanish have made it challenging to compare the letter-as-percept view against the grapheme-as-percept view using my experiments. Assuming the findings in the Spanish experiment were not the result of a Type I error, it seems likely that differences between the single- and double-vowel primes in the Spanish experiment (and by extension in Rey et al.'s (2000) experiments) were due to mechanisms in the reading process after the identification of abstract reading units.

It is still important, however, to see how single- and double-vowel facilitation compare to one another in English. If single vowels facilitate reaction times more than double vowels, an explanation will be in order. It will be necessary to explain why such an effect would occur in English but not in Spanish. Whatever explanation works, it will no longer be possible to appeal simply to a grapheme-as-percept explanation since that view predicted equal facilitation for single- and double-vowel primes in Spanish. It would be necessary to provide an alternative explanation that rests on internal components of models of normal English reading.

If there is equal facilitation for single- and double-vowel primes, then it may be possible to rule out the grapheme-as-percept view altogether. In this case, letters would be the fundamental reading unit from bottom to top, as it were. With these possibilities in mind, the experiment with English monolingual adults is presented below.

4.2.1 Participants

All of the participants for this experiment were undergraduate students at the University of Arizona, most of them taking a foreign language as a requirement of their degrees. But the participants selected for this experiment were native English readers who had either never studied Spanish or Italian (a language particularly close to Spanish in terms of orthography), or had done so for less than 1 year more than 5 years previously.

There were 33 participants who met these criteria. They all had normal or corrected vision. They received course credit for their participation.

4.2.2 Procedures

The materials for the English experiment are described next, along with the procedures. Every attempt was made to make the English materials parallel to the Spanish materials. The procedures were equivalent except for language.

4.2.2.1 Materials

The English items paralleled the Spanish items in most ways. But there were some differences that reflected English linguistic structures. Item statistics for English targets are summarized in Table 12 and for English primes in Tables 13. The complete set of items by condition for the English experiment can be found in Appendix D (p. 244) for the low-frequency targets, and in Appendix E (p. 245) for the high-frequency targets.

First, I will discuss targets. This set of 96 items included not only 5-letter monosyllabic words, but also 5- and 6-letter di- and tri-syllabic words. Among the targets, there were 47 five-letter words, and 49 six-letter words. Also, there were 47 monosyllabic (e.g., GRAFT), 42 disyllabic (e.g., RECORD), and 7 tri-syllabic targets (e.g., EDITOR). The mean number of syllables for all targets was 1.58 (SD = 0.63). In the YES responses, this was 1.56 (SD = 0.65); in the NO responses this was 1.60 (SD = 0.61). Targets and primes were matched by number of letters, but not number of syllables. These characteristics make the materials more comparable to the materials in Spanish, where monosyllabic 5-letter words (e.g., CRUEL) are much harder to find.

Word frequencies were determined using Kučera & Francis (1967). The high-frequency words comprised 25% of the targets. The overall mean frequency for high-frequency targets was 123.42 per million (SD = 44.61). The overall mean frequency for low-frequency targets was 3.67 per million (SD = 3.52). In the YES responses, the mean was 124.58 per million (SD = 56.03) for high-frequency targets, and 3.92 per million (SD = 3.60) for low-frequency targets. In the NO responses, the mean was 122.25 per million (SD = 31.90) for high-frequency targets, and 3.42 per million (SD = 3.47) for low-frequency targets.

TABLE 12. Item Statistics (Counts and Mean Frequencies) for English Targets, Adult Materials.

		Syllables			Letters		
Frequency	*n*	One	Two	Three	Five	Six	Mean frequency
High	24	6	17	1	12	12	123.42 (44.61)
Low	72	41	25	6	35	37	3.67 (3.52)
Total	96	47	42	7	47	49	33.60 (56.64)

Note. SD in parentheses.

Next, I will discuss primes. Item statistics for primes can be seen in Table 13. Among the double-vowel primes, sometimes the search letter was the left member of the pair (e.g., A → sn<u>a</u>il → TRASH) and sometimes the right member (e.g., A → pe<u>a</u>ch →

GRAFT). Overall, it appeared on the left-hand side in 45% of the cases, and on the right-hand side in 55 % of the cases. In the YES responses, these percentages were 46% and 54%, respectively. And in the NO responses, they were 45% and 55%, respectively.

As noted above, items varied from one to three syllables in length. The average number of syllables for all primes was 1.49 syllables (SD = 0.63). For the single-vowel primes, the average number was 1.48 (SD = 0.62). for the double-vowel primes, it was 1.35 (SD = 0.48). And for the control primes, it was 1.63 (SD = 0.73). It is worth noting that, unlike Spanish materials, the English materials were relatively balanced in the distribution of syllables among the various prime types.

All primes were low frequency. The mean frequency for all primes was 4.4 per million (SD = 4.17). In the YES responses, the mean frequency was 4.51 per million (SD = 4.53); in the NO responses it was 4.38 per million (SD = 3.79). The mean frequency for single-vowel primes was 4.34 per million (SD = 4.12). For double-vowel primes, it was 4.58 per million (SD = 4.00). For control primes it was 4.40 per million (SD = 4.43).

TABLE 13. Item Statistics (Counts and Mean Frequencies) for English Primes, Adult Materials.

Vowel prime type	Syllables: One	Syllables: Two	Syllables: Three	Position of search letter in double vowel: Left	Position of search letter in double vowel: Right	Mean frequency
Single (n=96)	53	37	6			4.34 (4.12)
Double (n=95[a])	61	34	0	43	52	4.58 (4.00)
Control (n=96)	47	37	12			4.40 (4.43)
Total	162	108	18	43	52	4.44 (4.17)

Note. SD in parentheses.
[a] One single-letter prime was mistakenly included as a double-vowel prime in the materials. This item was deleted from the analysis. Thus, the number of double-vowel primes was one less than the number of other primes.

The allocation of items to the various conditions of the experiment was identical to the Spanish experiment shown in Table 7 above (p. 97). The same is true for the breakdown by frequency, shown in Table 8 above (p. 98). And again, too few high-frequency items were included in the English experiment to draw any conclusions about frequency. Therefore, as in experiment 1, I report only results for the low-frequency items.

It is worth highlighting one last aspect of the English experiment. The duration of the masked prime had an extra advantage in the English materials that was irrelevant in the Spanish materials. The 33-ms prime masked primes in the English experiments helped circumvent a natural confound: The single-letter primes matched their targets phonologically more often than the double-vowel primes did. For example, the grapheme-phoneme correspondence for the vowel in the single-vowel prime, CREST, and the target, SPENT, are identical: E → /ɛ/. But the grapheme-phoneme correspondences in the double-vowel prime, FIELD, and the target, SPENT, are different: IE → /i/ vs. E → /ɛ/, respectively. Crucially for these materials, orthographic form effects usually predominate over phonological effects at short prime durations in most experiments. Phonological effects usually begin to emerge clearly only at priming durations above 60 ms (Davis, Castles, & Iakovidis, 1998; Ferrand & Grainger, 1992, 1993, 1994; Kouider & Dupoux, 2001; Ziegler et al., 2000).[41] So any effects in this experiment with 33-ms primes are at least less likely to be phonological in nature.

4.2.2.2 Task

The task for these participants was the same as it was for the Spanish monolingual adults, except that all oral and written instructions were in English. The English monolingual adults were also debriefed in English, and received course credit for their participation.[42]

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[41] For a different view of how early phonological effects occur relative to orthographic effects, see work by Frost and his colleagues (e.g., Frost, 1998, 2003; Frost et al., 2003; Lukatela & Turvey, 1994).

[42] Two laptop computers were used for all English monolingual adults. One was a *Toshiba Satellite A45-S121* running on *Windows XP*, and the other was a *Dell Inspiron 3000* running on *Windows 98*. The input devices were a *Saitek P880 Pad USB* game

4.2.3 Review of predictions

Again, it would be awkward to base the predictions for the English experiment on the findings of the Spanish experiment. With respect to syllable boundaries and pronunciation, the phonemic and syllabic nature of double vowels is much less uniform in English than in Spanish. So the explanations for the IDV facilitation effect in Spanish would make less clear predictions for English. Also, most researchers have had more difficulty finding whole-syllable effects in experiments using spoken or written English (e.g., Cutler et al., 1986; Ferrand, Segui, & Humphreys, 1997; Schiller, 1999). Thus, there is less reason to predict that the English results will parallel the Spanish results. If they did, then one would have to concede that there is something odd about the letter-detection task itself that causes the unpredicted effects, and explain the oddity if possible.

Assuming the results of the English experiment do not parallel those of Spanish, then it is possible to turn back, albeit more cautiously, to the original question posed in Chapter 3: Are letters or graphemes the basic perceptual reading unit? Any such discussion now will naturally be tempered by the results of the Spanish experiment. Detecting letters in words seems to draw on elements internal to the lexical processor.

Regardless, for the grapheme-as-percept view to be sustainable, the English experiment should still show a single-vowel benefit of some sort. This is because any inhibitory effect digraphs in English have at the perceptual stage should persist to the

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controller and a *Microsoft SideWinder Game Pad USB*. The *Toshiba Satellite* used both input devices, and the *Dell Inspiron* was used with the *Saitek* input device only.

decision stage. But even if such a difference is found, it is no longer reasonable to attribute it without reservation to perception. The difference could be due to some internal aspect of the lexical processor. If there is no single-vowel benefit, then it will be difficult to sustain a grapheme-as-percept view.

That having been said, it is useful now to review the basic predictions of the letter- and grapheme-as-percept views in the English experiment. The letter-as-percept view predicts that for YES responses, both single- and double-vowel primes will facilitate responses equally relative to control primes. This means also that there should be no single-vowel benefit. For NO responses, both primes types should inhibit responses equally, entailing no single-vowel detriment. In contrast, the grapheme-as-percept view predicts that, for YES responses, single-vowel primes will facilitate responses more than double-vowel primes. This implies the presence of a significant single-vowel benefit. For NO responses, single-vowel primes should inhibit responses more than double-vowel primes, entailing a single-vowel detriment. If there are no response congruency effects at all, then we can conclude that the participants could not extract information from the primes, and that the experiment did not measure what was intended.

4.2.4 Results

The same rejection, cutoff, and trimming procedures as in experiment 1 (p. 101) were applied to the data in this experiment. The data from participants with error rates above 20% were not included in the analyses (but in fact, no participant in this group had such a high error rate). All reaction times below 200 ms or above 1,000 ms were deleted.

And for each participant, reaction times were trimmed to ± 2SD from that participant's mean. The resulting mean reaction times for the English monolingual adults can be seen below in Figure 9. Mean errors, reaction times, facilitation, and benefit can be seen in Table 14.

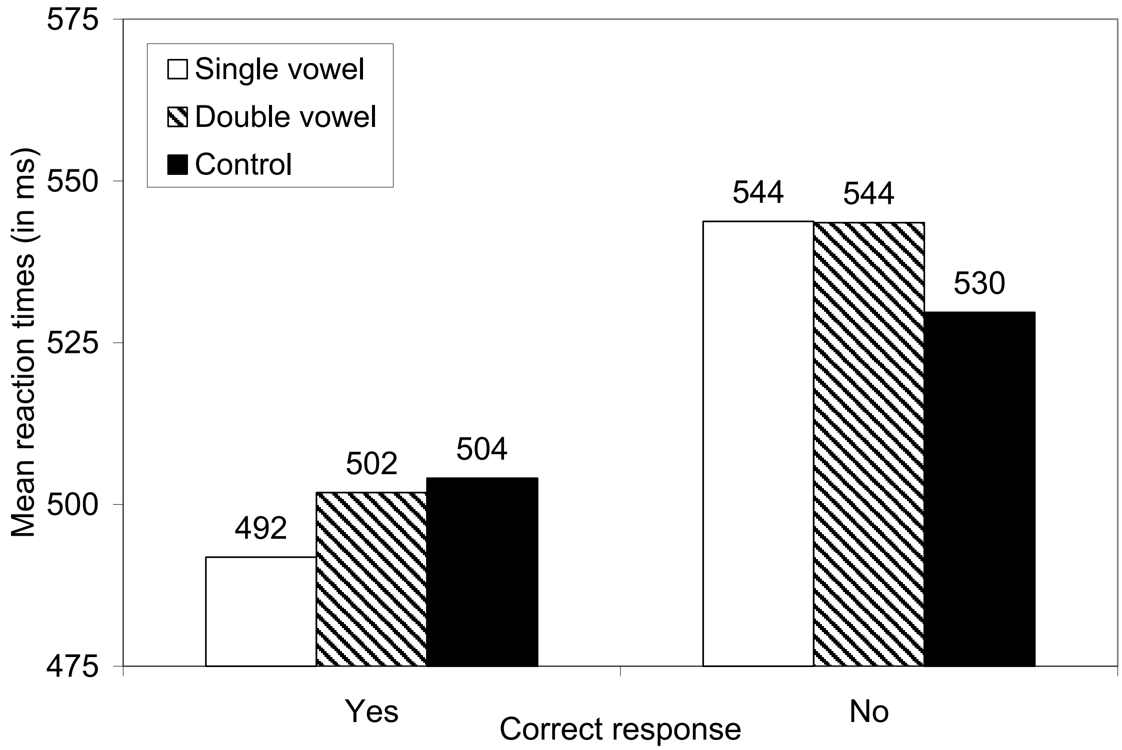

FIGURE 9. Mean reaction times (in ms) for English monolingual adults with 33-ms primes.

In the analysis of reaction times, a 2x3 factorial ANOVA (Response x Prime Type) showed a main effect for response. This was significant in both the participant and item analyses, $F_1(1,30) = 64.93$, $p < .0001$, $F_2(1,30) = 65.60$, $p < .0001$. There was no main effect for prime type by participant or by item, $F_1(2,60) = 1.14$, $p < .4$, $F_2(2,60) = 1.76$, p

< .2. Finally, there was a significant interaction between response and prime type. This was significant in both the analysis by participant and item, $F_1(2,60) = 4.63$, $p < .02$, $F_2(2,60) = 4.79$, $p < .02$.

Planned comparisons showed no significant differences for the YES responses. The closest was the 12-ms facilitation for the single-vowel primes, which was marginal in the analysis by item, and not significant by participant. However, there were significant differences in the NO responses. The 14-ms inhibitions for both the single- and double-vowel primes were significant both by participant and by item. No other comparisons were significant.

In the analysis of error rates, a 2x3 factorial ANOVA (Response x Prime Type) showed a main effect for response, but only in the analysis by participant, $F_1(1,30) = 4.84$, $p < .04$, and not in the analysis by item, $F_2(1,30) = 1.95$, $p < .2$. There was a marginal interaction between response and prime type, but only in the analysis by participant, $F_1(2,60) = 3.12$, $p = .0515$, $F_2(2,60) = 2.08$, $p < .15$.

TABLE 14. Mean Error Rates, Reaction Times (RT), Facilitation, and Benefit for English Monolingual Adults (N=33) with 33-ms Primes as a Function of Response and Prime Type.

Response and vowel prime type	Dependent measures: Error rate (%)		Dependent measures: RT (ms)		Facilitation (ms)	Benefit (ms)
YES						
Single	6.1	(6.3)	492	(84)	12	10
E→crest→SPECK						
Double	6.1	(7.6)	502	(81)	2	
E→field→SPECK						
Control	8.6	(9.4)	504	(81)		
E→block→SPECK						
NO						
Single	6.5	(8.6)	544	(86)	-14*	0
E→crest→STAMP						
Double	6.0	(7.2)	544	(73)	-14*	
E→field→STAMP						
Control	3.1	(5.2)	530	(82)		
E→block→STAMP						

Note. Facilitation = [Control]-[Single] and [Control]-[Double]. Benefit = [Double]-[Single]. SD in parentheses.
* Significant by participant and by item

4.2.5 Discussion

The first result to note is that, as in the experiment with Spanish monolingual adults, there is facilitation in the expected directions. That is, congruent primes tend to facilitate reaction times, and incongruent primes tend to inhibit them. This means that information from the primes affected the way that participants responded to targets. This tendency was stronger in English than in Spanish, where this was only true in the YES responses.

The results of the English experiment conform better to my original predictions than the results of the Spanish experiment do. A casual glance at Figure 9 would lead one to suspect that single- and double-vowel primes spur symmetrical congruency effects. That is, they seem to facilitate responses to targets in the YES responses, and inhibit them in the NO responses. However, the congruency effect is statistically significant only in the NO responses (an inhibitory effect). But this is enough to infer that the participants were using information from the primes, and that the experiment measured what was intended.

It is important to note that in the NO responses, single- and double-vowel primes are equally inhibitory relative to control primes. There is no single-vowel detriment. This result supports the letter-as-percept model. The weaker trends in the error data also seem to confirm the support for the letter-as-percept view. That is, there seems to be roughly equal facilitation for single- and double-vowel primes for the YES responses, and roughly equal inhibition in the NO responses.

But the fact that the effect in reaction times occurs only in the NO responses begs for an explanation. It is possible that the participants had a YES bias, accounting for their significantly faster YES responses as compared to NO responses. Since the target (the backward mask) replaced the stimulus from the prime relatively quickly (after 33 ms), the accelerated YES responses may have provided participants too small a window from which to process the information from the primes very well. Likewise, the delay in the NO responses would have allowed the participants to process the primes more thoroughly. This may be why the congruency effect only surfaced clearly in the NO responses. If this is the case, then facilitation effects for YES responses should begin to show up when prime durations are lengthened.[43]

Furthermore, it is possible that the digraph effect that Rey et al. (2000) found was not at the perceptual level, but rather further along the lexical processing route than the abstract-unit identification stage. Many researchers using masked-priming have found that orthographic effects tend to precede phonological effects (e.g., Davis, Castles, & Iakovidis, 1998; Kouider & Dupoux, 2001). If Rey et al.'s digraph effect was not due strictly to perception, but to letter-to-grapheme conversion (which is hard to distinguish from letter-to-phoneme conversion), a single-vowel benefit should appear at longer prime durations (beneficial in YES responses and detrimental in NO responses). This was the focus of the next two experiments, presented together.[44]

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[43] Recall that this is the opposite of what happened in the Spanish experiment. In that experiment, however, mean reaction times were much longer, which would have given the participants time to process the information in the YES responses.

[44] Before moving on, another modification to this experiment deserves mention. At one point, some colleagues noted that guiding the participant to the relevant vowel with the colored hashmark might have weakened a true single-vowel benefit by splitting the grapheme up for the participant, as it were. To test this, another version of the experiment with 33 ms primes was carried out, but without the red hashmark (i.e., all the hashmarks in the forward mask were black). There were no statistically significant results this experiment.

4.3 Experiments 2B and 2C: English adults with 48- and 67-ms primes

Experiment 2A was repeated with prime durations of 48 and 67 ms. The purpose was to test whether increasing the prime duration would result in the appearance of facilitation and benefit effects that were latent with 33-ms primes.

4.3.1 Participants

Unlike in experiment 2A, it was not feasible to continue selecting participants who had either never studied Spanish or Italian, or had not done so recently or intensively. Most of the participants for this experiment were students at the University of Arizona taking a foreign language as a requirement of their degrees. Many of them had studied some Spanish, so the results will be interpreted accordingly. That said, selecting only English monolingual adults is an unusual step in psycholinguistic experiments. In fact, the participants in this experiment are much more typical of the sort that provide the data for most experiments done in English.

There were 27 participants who qualified for experiment 2B and 24 participants for experiment 2C. All had normal or corrected vision, and none had been exposed to Spanish before the age of 9. They received course credit for their participation.

4.3.2 Procedures

The materials and task were the same for this experiment as for experiment 2A, except that the duration of the prime was set at 48 ms for experiment 2B and 67 ms for experiment 2C.

4.3.3 Results

The same rejection, cutoff, and trimming procedures as in experiment 1 (p. 101) were applied to the data in these experiments. The data from participants with error rates above 20% were not included in the analyses (but no participant in this group had such a high error rate). All reaction times below 200 ms or above 1,000 ms were deleted. And for each participant, reaction times were trimmed to ± 2SD from that participant's mean. The resulting mean reaction times for the 48-ms primes can be seen in Figure 10 below. Mean errors, reaction times, facilitation, and benefit can be seen in Table 15. The same can be seen, respectively, for the 67-ms experiment in Figure 11 and Table 16. The results for each is discussed in turn.

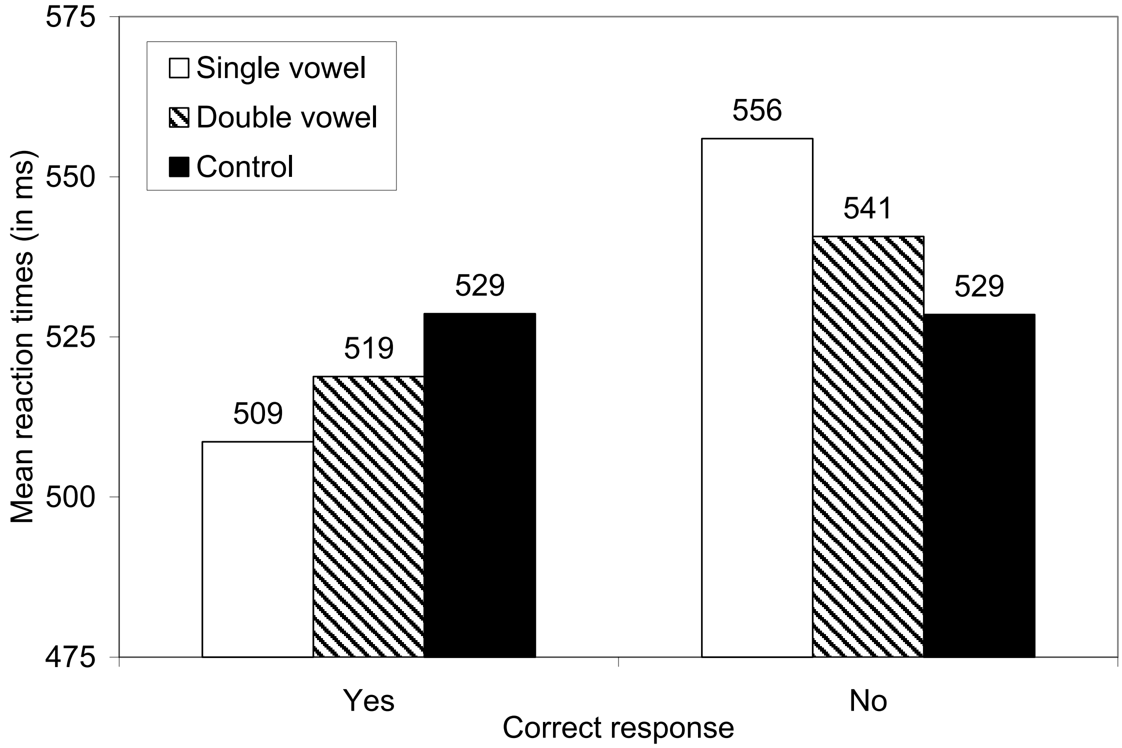

FIGURE 10. Mean reaction times (in ms) for English adults with 48-ms primes.

In the experiment with 48-ms primes, the 2x3 factorial ANOVA (Response x Prime Type) showed a main effect for response, significant by both participant and item, $F_1(1,24) = 12.57$, $p < .002$, $F_2(1,30) = 16.96$, $p < .0003$. There was no main effect for prime type, $F_1(2,48) < 1$, $F_2(2,60) = < 1$. However, there was a significant interaction between response and prime type. This was significant by participant and item, $F_1(2,48) = 12.72$, $p < .0001$, $F_2(2,60) = 11.21$, $p < .0001$.

Planned comparisons showed significant differences in the YES responses. The 20-ms facilitation for the single-vowel primes was significant by both participant and item. The 10-ms facilitation for the double-vowel primes was significant by item, but not by participant. Finally, the 10-ms single-vowel benefit was not significant, though it was marginal in the analysis by item.

There were also significant differences in the NO responses. The 27-ms inhibition for the single-vowel primes was significant both by participant and by item. The 12-ms inhibition for the double-vowel primes was significant by item but not by participant. The 15-ms single-vowel detriment was significant by participant, but only marginal by item.

The mean percent error rates in the experiment with 48-ms primes roughly paralleled the mean reaction times. That is, smaller mean errors were associated positively with faster mean reaction times. But the statistical analysis did not show any main effects or interactions that were significant by both participant and item.

TABLE 15. Mean Error Rates, Reaction Times (RT), Facilitation, and Benefit for English Monolingual Adults (N=27) with 48-ms Primes as a Function of Response and Prime Type.

	Dependent measures					
Response and vowel prime type	Error rate (%)		RT (ms)		Facilitation (ms)	Benefit (ms)
YES						
Single	3.7	(5.8)	509	(109)	20*	10
E→crest→SPECK						
Double	5.2	(7.4)	519	(119)	10[I]	
E→field→SPECK						
Control	6.8	(7.7)	529	(103)		
E→block→SPECK						
NO						
Single	3.7	(7.8)	556	(98)	-27*	-15[P]
E→crest→STAMP						
Double	4.2	(5.1)	541	(110)	-12[I]	
E→field→STAMP						
Control	1.9	(3.7)	529	(104)		
E→block→STAMP						

Note. Facilitation = [Control]-[Single] and [Control]-[Double]. Benefit = [Double]-[Single]. SD in parentheses.
* Significant by participant and item
[P] Significant by participant
[I] Significant by item

In the experiment with 67-ms primes, depicted below in Figure 11, and summarized in Table 16, a 2x3 factorial ANOVA (Response x Prime Type) showed a main effect for response. This was significant by participant and item, $F_1(1,21) = 28.85$, $p < .0001$, $F_2(1,30) = 40.81$, $p < .0001$. There was no main effect for prime type, $F_1(2,42) < 1$, $F_2(2,60) = < 1$, but there was a significant interaction between response and prime type. This was significant in both analyses, $F_1(2,48) = 10.19$, $p < .0002$, $F_2(2,60) = 10.36$, $p < .0001$.

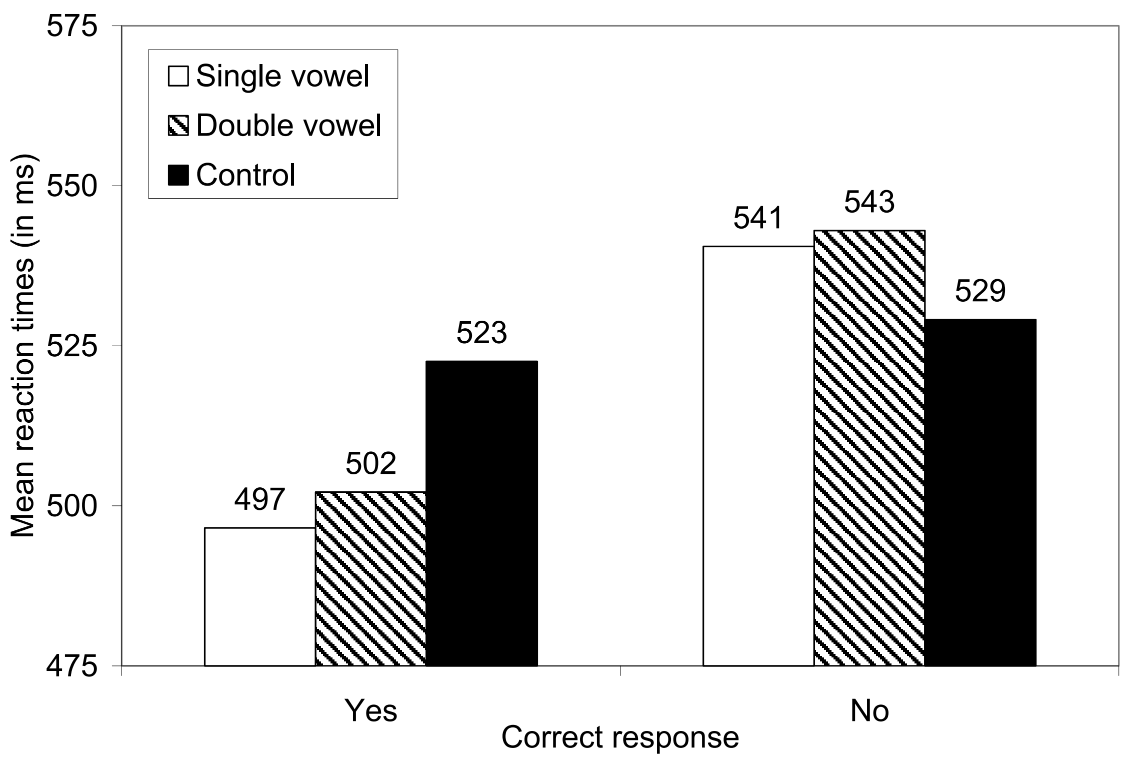

FIGURE 11. Mean reaction times (in ms) for English adults with 67-ms primes.

Planned comparisons showed significant differences in the YES responses. The 26-ms facilitation for the single-vowel primes was significant by both participant and item. The 21-ms facilitation for the double-vowel primes was also significant by participant and item. There were weaker, but significant, differences in the NO responses.

The 12-ms single-vowel inhibition and the 14-ms double-vowel inhibition were significant by item.

The mean error rates in the experiment with 67-ms primes did not parallel the results with reaction times, as in previous experiments. Nor were there any significant main effects or interactions.

TABLE 16. Mean Error Rates, Reaction Times (RT), Facilitation, and Benefit for English Monolingual Adults (N=24) with 67-ms Primes as a Function of Response and Prime Type.

	Dependent measures			
Response and vowel prime type	Error rate (%)	RT (ms)	Facilitation (ms)	Benefit (ms)
YES				
Single	6.6 (6.9)	497 (73)	26*	5
E→crest→SPECK				
Double	4.9 (6.0)	502 (81)	21*	
E→field→SPECK				
Control	6.9 (9.4)	523 (65)		
E→block→SPECK				
NO				
Single	5.8 (8.0)	541 (82)	-12[I]	2
E→crest→STAMP				
Double	6.8 (7.1)	543 (75)	-14[I]	
E→field→STAMP				
Control	4.6 (5.6)	529 (72)		
E→block→STAMP				

Note. Facilitation = [Control]-[Single] and [Control]-[Double]. Benefit = [Double]-[Single]. SD in parentheses.
* Significant by participant and item
[I] Significant by item

4.3.4 Discussion

It seemed to make no difference that these participants had been exposed to more Spanish, on average, than the participants in the experiment with 33-ms primes. This is because the trend with the 48-ms primes is in the opposite direction: A single-vowel benefit seems to be emerging, however weakly. This result provides some support for the grapheme-as-percept view. To review the results at 48 ms, facilitation from the single-vowel primes seemed to be clearer for YES responses than that of the double-vowel primes. The same was true of the NO responses, where inhibition from the single-vowel primes seemed to be clearer than that of the double-vowel primes. Although there was no significant single-vowel benefit in the YES responses, there was a weak single-vowel detriment in the NO responses in the analysis by participant. Thus, the statistical analysis of the experiment at 48 ms suggests that there may have been a weak single-vowel benefit in the YES responses that was stifled in the experiment at 33 ms by the combination of a short prime duration and a positive response bias. On this interpretation, the extra processing time introduced by the longer prime duration prevented participants from responding before they had processed the prime more thoroughly.

However, this weak single-vowel benefit at 48 ms seemed to disappear in the experiment at 67 ms, where double-vowel primes became just as facilitative as the single-vowel primes for YES responses, and just as inhibitory for NO responses. This change at 67 ms makes it difficult to connect the outcome of the masked priming experiment at 48 ms with the experiments from Rey et al. (2000), which used no priming at all. Since the participants could see the double vowels in the targets in Rey et al.'s study, one would predict that the effect should grow stronger as prime durations increase. In other words, it might be difficult to explain why the effect occurs at 48 ms, disappears at 67 ms, and then reappears only when the participants can clearly see the conditions in the targets (i.e., as in Rey et al.'s experiments).

The answer could lie in the fact that the experiments presented here are, indeed, priming experiments, and that the Rey et al. (2000) experiments are not. One might appeal to awareness. Primes presented for less than 50 ms usually go completely unnoticed by participants, but primes presented for 60-67 ms are usually noticed in some way, even if the participant cannot identify them (Forster, 1998; Forster, Mohan, & Hector, 2003). Awareness of the prime at 67 ms (which must be assumed since it was not measured) may have allowed a set of lexical or grapheme candidates stimulated by the prime to be resolved in some way so that they did not interfere with the processing of the target. Since all the targets contained single vowels (no double vowels), the participants would have seen no differences among targets as long as the lexical candidates or graphemes activated by the primes had been dismissed in some way through awareness.

There is precedent for this sort of explanation. For instance, prime awareness was used to explain how masked priming in lexical decision produces robust form-priming effects at prime durations below 50 ms, but not at longer prime durations (Forster, 1999; Forster & Veres, 1998).[45] When participants were unaware of the form prime, the target was activated as a lexical candidate, and it remained active when the target appeared. This led to priming. But when participants were aware of the prime, they were able to

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[45] Form priming is when the prime and the target differ by one letter (e.g., CRASS-CLASS, PREY-PRAY, LEOTARD-LEOPARD).

resolve it, so the mental target (a lexical candidate generated by the prime) was inactive by the time the physical target appeared on the computer screen. The result was no priming. If the set of candidates activated by the prime can be dismissed through awareness of the prime, then the congruency effects in the 67-ms experiment are pure, reflecting only differences in the subconscious decisions made on the primes.

If one also concedes that YES responses in the 33-ms experiment were premature with respect to processing of the prime, then it is possible that 48 ms would be the prime duration near which grapheme effects would emerge. But this explanation still has to be reconciled with the finding that there was no single-vowel detriment for the NO responses in the 33-ms experiment. In fact, there was no reaction-time difference at all between the single- and double-vowel primes though the inhibition was significant for both. It is, therefore, difficult to maintain that graphemes are being processed at the level of perception. One is forced to ask how, then, could a letter-as-percept model account for the results?

The predictions of the letter-as-percept view are consistent with the results of the experiments with 33- and 67-ms primes. There are no apparent conflicts to the view. It is a little harder to explain the results of the experiment with 48-ms primes. But if the letter-detection task takes place along a nonlexical route, and graphemes can be activated at prime durations less than 50 ms, then one might be able to explain the weak trend here in terms of letter-to-grapheme (or -phoneme) conversion.

Recall from my discussion of the English materials (Section 4.2.2.1) that, in terms of phonology, the relevant vowel in the targets matched the relevant vowel in the single-vowel primes more often than it matched the relevant vowel in the double-vowel primes. It could be the case that the lack of a single-vowel detriment in the NO responses at 33 ms was because only orthography was processed. The appearance at 48 ms of a weak benefit in YES responses and a weak detriment in NO responses could reflect emerging phonological representations, activated by letter representations. Phonological activation would facilitate reaction times for YES responses after single-vowel primes more than after double-vowel primes, and vice-versa. Again, the disappearance of the benefit at 67 ms could reflect awareness of the primes and their consequent irrelevancy to responses to targets.

But also recall that Rey et al. (2000) controlled for phonemic similarity in their experiment 2 by making sure that the name of the search letter (e.g., A → /e^{j}/) was present in both the single-vowel and vowel-digraph conditions (e.g., A → TRADE, A → BREAK). They still found a digraph effect. Taking these findings into account, it would be more prudent to appeal simply to graphemic effects.

Interestingly, a speculative account of the dual-route cascaded model (DRC; Coltheart et al., 1993, 2001) might just explain the effects found so far in the English experiments.[46] The 33-ms prime was probably too short for graphemes to be activated

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[46] My account here is speculative because the nonlexical route of the DRC, as it is currently formulated, is not designed to handle polysyllabic words like those used in my

along the nonlexical route. The only possible effect at this stage would involve the perception of letters, which would account for the equal inhibition in NO responses for single- and double-vowel primes (no single-vowel detriment). But the 48-ms prime duration probably allowed for some activation of graphemes, which introduced competition for letter recognition, exactly as explained by Rey et al. (2000) but at a later stage. The 67-ms prime duration allowed participants to become aware of the primes. This allowed them to dismiss the graphemes that had been activated by the letters in the prime and return, uninhibited, to the task of letter identification in the target.

But for this to be true on a dual-route model, it is also necessary to make sure that the letter-detection task takes place along the nonlexical route, and not along the lexical route. If one can show a digraph effect in letter detection without a frequency effect, then one can assume that lexical entries did not play a role in the task. In fact, Rey et al. (2000) did this. They did not find any frequency effects in their experiments, and thus attributed the effects in their experiment to the nonlexical route. There were not enough high frequency items in my masked-priming materials,[47] but it will still be useful to see if it is possible to replicate the effects in the Rey et al. study without frequency effects. If it is found that high-frequency items are responded to faster than low-frequency items, then

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experiments (Coltheart et al., 2001, pp. 250-251). Nonetheless, the experiments here focus on letters, not words, so I feel confident in assuming that the monosyllabic constraint in the DRC's design makes little difference.

[47] Nor, as noted above, was the frequency of the primes manipulated. High- and low-frequency targets would have provided little in terms of determining whether the task was completed along the lexical or nonlexical routes, or both.

one can be reasonably sure that the participants are using the lexical route to carry out their decisions. If there is no frequency effect, then it is more likely that they are using the nonlexical route. This is covered in the next experiment.

4.4 Experiment 2D: English adults on replication of Rey et al. (2000)

4.4.1 Participants

Participants were 40 undergraduate students at the University of Arizona who received class credit for participating in the experiment. They had roughly the same background characteristics as the participants in experiments 2B and 2C.

4.4.2 Procedures

This experiment differed only minimally from Rey et al.'s (2000) experiment 1A. Differences are highlighted below.

4.4.2.1 Materials

Most of the materials in this replication are the same as in Rey et al. (2000), experiment 1A. The 5-letter, monosyllabic target words either had a single vowel letter representing the nucleus (single-vowel targets), or a double vowel letter representing the nucleus (digraph targets). In turn, these were divided into low- and high-frequency lists. There were 15 representative items for each condition. The resulting item statistics for the replication are displayed in Table 17 below. The difference in item statistics between these modified materials and the materials used by Rey et al. (2000) are trivial.

The materials in my experiment were different from Rey et al's in one way however. Some of the items in Rey et al.'s experiment contained vowel digraphs in addition to a "silent E" ending (e.g., lease). The so-called silent E is considered a split digraph since it usually affects the phonemic quality of the nearest nonadjacent written vowel to the left (e.g., compare SHAM /ʃæm/ and SHAME /ʃe^{j}m/). When the silent E is appended to a word with an internal vowel digraph (LEASE /lis/, MAIZE /me^{j}z/), its role is not so clear. Thus, it seemed prudent to rule out any effects that might occur because of ambiguous rules of orthography. Digraph items with silent Es were replaced with items more like the others in the digraph set. A complete list of these replacements, along with the other items in the experiment, is included in Appendix F (p. 246).

TABLE 17. Statistics for Modified Materials in Replication of Rey et al. (2000).

Condition			Statistics	
Response	Frequency group	Target vowel type	*n*	Frequency
YES	Low	Single	15	4.67 (4.73)
		Digraph	15	3.07 (3.15)
		Split digraph[a]	15	3.80 (3.80)
	High	Single	15	93.13 (60.31)
		Digraph	15	102.27 (78.93)
NO	Mixed	Mixed	75	35.08 (71.60)

Note. SD in parentheses.
[a] A split-digraph target vowel type was added to this experiment, but is not relevant here.

4.4.2.2 Task

The replication was carried out as in Rey et al. (2000) with superficial differences other than the ones noted in Materials. The sequence of stimuli, covered at the end of Chapter 2 (Section 2.4), are repeated here for convenience. Participants saw the search letter (A, E, I, or U) at the beginning of each trial for 700 ms.[48] The search letters were

[48] This experiment was not presented on a laptop computer, but on a desktop. Responses were made with a button box.

presented pseudo-randomly, following Rey et al. (2000).[49] The search letter was followed by a fixation point (:) for 1,000 ms. The target word was then presented for 30 ms, followed by a blank screen for 70 ms. This 30+70-ms sequence gave the impression that the word had been on the screen for 100 ms, long enough for proficient readers to recognize. After the 70-ms blank screen, the participants saw the pattern mask (ØØØØØ) until they responded or a timeout occurred (at 2,000 ms). The software program DMDX (Forster & Forster, 2003) recorded errors and reaction times measured from the presentation of the target word.

4.4.3 Predictions

If what I have outlined above is accurate, then the various effects found so far at various prime durations have been due to letter-to-grapheme (or -phoneme) processes. If so, then the results from Rey et al. (2000) should replicate perfectly. That is, it should take participants longer to respond to letters embedded in digraphs, and there should be no frequency effect.

4.4.4 Results

To make this experiment more comparable with the others in this dissertation, the same rejection, cutoff, and trimming procedures as in experiment 1 (p. 101) were applied to the data in these experiments. The data from participants with error rates above 20%

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[49] Note that this pseudo-random presentation contrasts with the other experiments in this dissertation. Indeed, some search letters (e.g., A) were used much more than others (e.g., E), so perfect randomization was not possible.

were not included in the analyses (but no participant in this group had such a high error rate). All reaction times below 200 ms or above 1,000 ms were deleted. And for each participant, reaction times were trimmed to ± 2SD from that participant's mean. The resulting mean reaction times can be seen in Figure 12. Mean errors, reaction times,facilitation, and benefit can be seen in Table 18.

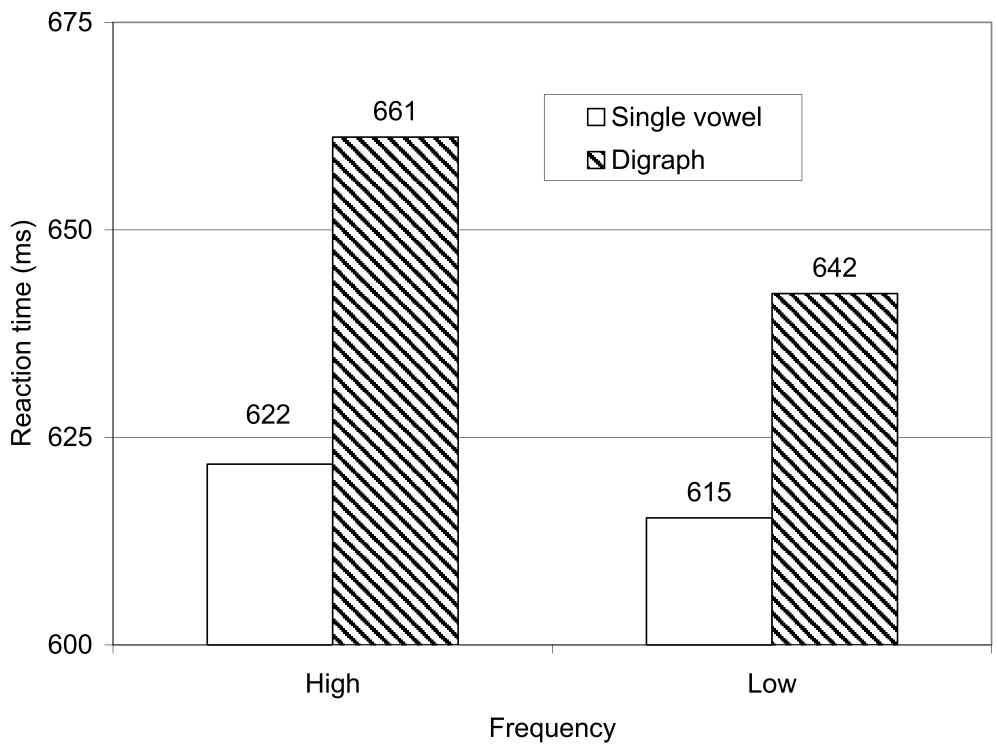

FIGURE 12. Mean reaction times (in ms) for English adults on replication of Rey et al.'s (2000) experiment 1A.

A 2x2 factorial ANOVA (Frequency x Target Vowel Type) showed a significant main effect for frequency, but only in the analysis by participant, $F_1(1,39) = 6.13$, $p < .018$, $F_2(1,14) = 1.79$, $p < .21$. For target-vowel type, there was a very significant effect by both participant and item, $F_1(1,39) = 40.37$, $p < .0001$, $F_2(1,14) = 63.82$, $p < .0001$. There was no significant interaction.

The error data are worth noting. There was a main effect for frequency, but only in the analysis by item, $F_1(1,39) = 1.32$, $p < .26$, $F_2(1,14) = 5.09$, $p < .041$. There was no main effect for target-vowel type in either analysis. But the interaction between frequency and target-vowel type was significant by item, and marginal by participant, $F_1(1,39) = 3.90$, $p < .0554$, $F_2(1,14) = 5.71$, $p < .032$.

TABLE 18. Mean Error Rates and Reaction Times (RT) for English Adults (N=40) on Replication of Rey et al. (2000) as a Function of Frequency and Target Vowel Type.

Frequency and target vowel type	Error rate (%)		RT (ms)	
HIGH				
Single	3.2	(4.8)	622	(119)
U→TRUST				
Digraph	5.5	(6.7)	661	(121)
U→COUNT				
LOW				
Single	3.8	(5.6)	615	(114)
U→CRUMB				
Digraph	2.8	(4.9)	642	(114)
U→VAULT				

Note. SD in parentheses.

4.4.5 Discussion

This experiment replicated the results of Rey et al. (2000) quite well. This is not surprising since the materials were the same except for the replacement of the ambiguous digraphs with non-functional split digraphs. On the interpretation that there is no frequency effect at all in this experiment, one can conclude that decision-making on the task does not rely on the lexical route. This would confirm the conclusions of Rey et al. (2000) that letter-detection takes place along the nonlexical route. But taken together with the other results in this section, it suggests that the effect occurs not at the perceptual level, but afterwards in a graphemic/phonological activation stage.

4.5 Summary

In this section, I summarize the findings in this chapter. I will begin by noting the importance of the consistent congruency effects across all experiments. I will then review the results of the Spanish and English experiments in turn. Lastly, I will show how the findings from the two languages do not necessarily conflict.

First, it is important to note that there were congruency effects in the expected directions in all the masked-priming experiments thus far. This consistency suggests that the participants were processing information from the primes in order to make decisions on targets. This is important since it is now possible to conclude that participants were gathering either letter-based information, or grapheme-based information, or both from the primes at all prime durations. It remains to be argued how they were using letter- or grapheme-based information (or both) and when (i.e., at which prime durations).

I will now review the Spanish results. If the grapheme-as-percept view or letter-as-percept views are correct, then in the Spanish masked-priming experiment, single- and double-vowel primes for YES responses should have facilitated reaction times equally relative to controls. In the NO responses, the two prime types should have been equally inhibitory relative to controls.

Surprisingly however, the double-vowel primes facilitated responses significantly more than single-vowel primes for YES responses. There were no significant differences in the NO responses. In order for either view to be correct, it is necessary to appeal to recent findings in Spanish word recognition suggesting that both syllables and abstract syllable structure are critical to word-identification in Spanish. If these components play such a role, then congruency of abstract syllable structure between single- and control-vowel primes on the one hand, and targets on the other, may have inhibited responses to targets by helping perpetuate or reinforcing syllable candidate activation. This in turn would have led to increased competition among syllable candidates during letter identification, and slower reaction times. In contrast, the double-vowel primes would have provided incongruent abstract syllable structure relative to targets, thereby minimizing persistence or reinforcement of syllable candidates activated in the target.

The results for the English experiment were very different. And at first blush, the explanation for those results could be seen as incompatible with the explanation for the Spanish results. But the recent theories about the varying role of phonology in word recognition across languages may help explain the discrepancy. First, I will briefly review the findings from the English experiments.

As in the Spanish experiment, the congruency effect appeared with 33-ms primes, at least in the NO responses. In fact, it appeared pretty consistently, and in the right directions, at all prime durations. It is reasonable to conclude, then, that the masked primes in the English experiments also served to activate information useful to making decisions about the presence or absence of particular letters.

With 33-ms primes, the only significant differences were in the NO responses. But there seemed to be equal inhibition from the single- and double-vowel primes relative to the control primes. There was no trace of the single-vowel detriment for NO responses that the grapheme-as-percept view would predict. This suggests that there is no early orthographic effect from multi-letter graphemes, just letters. This conflicts with Rey et al.'s (2000) conclusion that graphemes are the basic reading unit.

But it was possible that the failure to find the effect in the YES responses was due to the very short duration of the prime combined with a positive response bias. This combination may have made it difficult for participants to gather sufficient information from the primes to show the predicted effects in the YES responses. For this reason, the same experiment was run at longer prime durations.

With 48-ms primes, single-vowel benefits and detriments in the YES and NO responses, respectively, emerged weakly. With 67-ms primes, all single-vowel benefits and detriments disappear: Single- and double-vowel primes showed equal facilitation and inhibition in the YES and NO responses, respectively. It seems that the weak single-vowel benefit (if any) emerges within a narrow window of prime-durations (around 48 ms), and then disappears. The appearance and subsequence disappearance of this ostensible single-vowel benefit may be explained by letter-grapheme activation along a nonlexical route in conjunction with prime awareness.

The single- and double-vowel primes may have activated first letters and then graphemes along the non-lexical route. The effect of letters only was seen at 33 ms, whereas the effect of graphemes emerged at 48 ms. The late activation of graphemes is exactly what the dual-route cascaded model would predict. But awareness (again, assumed in my experiment, not measured) allowed the participants to discard the graphemes in the primes in order to focus more efficiently on the targets, which did not differ in general.

The last experiment in English was a replication of Rey et al.'s (2000) experiment 1A. The replication worked: Search letters embedded in vowel-digraph targets took longer to respond to than those embedded in single-vowel targets. Thus, the single-vowel benefit re-emerged (albeit with different materials). This result and the results of the masked-priming experiments make sense if one assumes that the single-vowel benefit is the result of letter-to-grapheme activation, akin to normal operations on the nonlexical route of the dual-route cascaded model (as explained above).

Another way of conceptualizing this is as follows. When there were congruency effects, but no single-vowel benefit or detriment, then graphemes were inactive. This happened on two occasions: (a) when the prime duration was too short (33 ms), and only orthographic (letter) information was available; and (b) when the graphemic activity generated by the letters had been rendered irrelevant to decisions on the target via awareness (the 67-ms experiment). In contrast, when there were single-vowel benefits or detriments in addition to congruency effects, graphemes were active. This happened on two other occasions: (c) when the letters of the prime had sufficient time to activate graphemes along the nonlexical route (the 48-ms experiment); and (d) when the targets themselves carried the graphemic information (in the Rey et al. (2000) replication). Overall then, the data seem to support the letter-as-percept view at the expense of the grapheme-as-percept view. The grapheme effects are probably attributable to letter-to-grapheme operations along the nonlexical route.

As noted above, however, this explanation ostensibly conflicts with the explanation for the IDV facilitation effect in the Spanish experiment. There, I argued that the incongruent abstract syllable structure between prime and target led to less interference in detecting letters from among active syllable candidates. Importantly, the 33-ms prime was long enough to activate such phonological representations. In the English experiments, I am arguing differently: namely, that activation of multi-letter graphemes in English leads to more competition unless the prime duration is too short or too long. In this case, the 33-ms prime was to short; more time was needed to activate phonological or graphemic representations. How can these two views be made compatible?

They may be compatible if it is assumed that phonological activation happens faster in shallow orthographies than in deep orthographies. The weak version of the orthographic-depth hypothesis (Frost, Katz, & Bentin, 1987; Katz & Frost, 1992), or alternatively, the universal phonological principle (Perfetti, 2003; Perfetti, Zhang, & Berent, 1992) can make sense of the difference. According to the weak version of the orthographic-depth hypothesis, phonology should play a relatively major role in visual word recognition in shallow orthographies (e.g., Serbo-Croatian, Spanish, German), but a more minor role in deep orthographies (e.g., Chinese, Hebrew, English). According to the universal phonological principle, all readers of all orthographies invoke phonology in one way or another to derive meaning from print, but how it is done depends on how the orthography is structured relative to the (phonological) mental lexicon. These two hypotheses are also consistent with Ziegler and Goswami's (2005) psycholinguistic grain-size theory discussed in Chapter 2 (Section 2.3.3).

All these hypotheses are relatively young and have not been tested thoroughly. But each allows, at least logically, for the possibility that phonological activation along the nonlexical route can happen more rapidly in shallow orthographies than in deep orthographies. Thus, in Spanish, phonological activation along the nonlexical route would be fast. In contrast, phonological activation in English is slower and more cumbersome. This results in graphemic competition that emerges relatively late (e.g., some time after 33 ms), and abates only when awareness sets in (e.g., at 67 ms), paralleling the late appearance and then disappearance of the weak single-vowel benefit.

At present, this explanation is stipulative. It remains to be seen whether it can be supported empirically.

The next chapter addresses the third issue mentioned at the very beginning of Chapter 1: transfer of alphabetic processing knowledge. Since Spanish and English share the roman alphabet, it is very possible that native readers of Spanish will transfer their Spanish alphabetic processing knowledge to English, at least when they begin to read it. Likewise, native English readers should transfer their alphabetic processing knowledge of English to Spanish, at least in the beginning. If it turns out they are transferring such processing knowledge, it will be interesting to see whether it persists in more proficient second-language (L2) readers. Since alphabetic processing knowledge is implicit knowledge, L2 readers may never develop the alphabetic processing knowledge that first-language (L1) readers of the language have. On the other hand, such knowledge may not be so difficult to acquire over time. This is the focus of the next chapter where I report on tests done with two groups of bilinguals: native Spanish readers doing the masked-priming experiment in English (with 33-ms primes), and native English readers doing the Spanish version of the experiment. It is also the focus of part of Chapter 6 when I test Spanish-dominant bilingual children doing the task in English. I present that study separately because of the differences in materials and task that were necessary to make the experiment work with much younger participants.

CHAPTER 5 STUDY OF ADULT BILINGUALS

I start this chapter by reviewing some of the recent research regarding transfer of reading processes across languages. I then present the results of English-dominant bilinguals doing the experiment in Spanish (i.e., experiment 1 in Section 4.1). High and low Spanish-proficiency groups are analyzed separately. The experiment following that is Spanish-dominant bilinguals doing the experiment in English (experiment 2A from Section 4.2). Similarly, high and low English-proficiency groups are analyzed separately. The chapter ends with a discussion of whether there was transfer, among which groups, and how the results fit in to what has been discovered so far in this dissertation.

5.1 Empirical foundations

Graphemes in different languages often represent linguistic elements at different levels. For example, Chinese characters represent morphemes; Japanese Kana represents syllables, or moras; Korean Hangul represents phonemes and syllables simultaneously, and Arabic Abjad represents phonemes (consonants and limited vowel information). It is possible that having learned to read in one's first language (L1) will, in some way, affect how one learns to read one's second language (L2). It is reasonable to predict strong transfer between writing systems like those just mentioned, the graphemes of which do not represent the same linguistic levels (e.g., Chinese to English, Arabic to Japanese). Indeed, some researchers have already concentrated on transfer among such writing systems. Koda, Geva, and their colleagues have found effects of such transfer in many of their studies (e.g., Akamatsu, 1999, 2003; Koda, 1989, 1995, 1999; Muljani, Koda, & Moates, 1998; Wang & Geva, 2003; Wang & Koda, 2005).

For example, Akamatsu (1999) compared lowercase words to words presented in alternated case (aLtErNaTeD cAsE) in an English naming task with four participant groups using English as a second language (ESL). Each L2 group varied according to the form of their L1 orthography. One group was Iranian, who represent Farsi with a consonant-based alphabet (Arabic script). A second group was Japanese, who use a combination of morpheme- and syllable-based graphemes (Kanji and Kana, respectively). A third group was native Chinese from the People's Republic of China, who use morpheme-based graphemes. The last group were native English-reading controls. All participants had high vocabulary and reading-comprehension sub-scores on the Test of English as a Foreign Language (the TOEFL). One would predict that alternating case should affect native readers of English the least since they should have more mastery over English orthography. If ESL learners apply written-word recognition strategies from their L1 to their L2, one would expect native Iranians, by sole virtue of the fact that they use an alphabet in their L1, to have a slight advantage over native Japanese and Chinese when reading words in mixed case. Akamatsu found that although the Japanese were significantly faster than the Iranians at naming all-lowercase words, they were no faster than Iranians at naming alternated-case words. This suggests that alternating case was less disruptive to Iranians than to Japanese. A similar interaction held true between the Iranians and the Chinese, though the Iranians were faster than the Chinese in both case formats. Akamatsu reasoned that the Japanese and Chinese were probably adopting whole-word strategies from their respective L1 writing systems to recognize English words, whereas the Iranians were using alphabetic strategies.

Another interesting cross-orthographic difference that might invite transfer is where the two writing systems share a level of representation (e.g., alphabets, which represent phonemes), but differ on how those units are represented. Examples of such differences include the following languages: (a) English or Russian, which use graphemes to represent both consonants and vowels; (b) Hebrew or Arabic, which use graphemes to represent consonants, with limited vowel information; and (c) the Korean Hangul writing system, which uses graphemes to represent syllables and phonemes simultaneously.

Ryan and Meara (1991) examined this issue. They tested whether native readers of Arabic transferred their L1 processing knowledge to their L2, English. In the Arabic Abjad, words are spelled as consonant strings with limited vowel information. The three long vowels of Arabic have their own graphemes, but the three short vowels must be represented by diacritics on the consonants, which is rare (Rogers, 2005). Furthermore, for speakers of many Arabic dialects, the written long vowels must often be ignored because they have changed across dialects much faster than the script has been allowed to change. Thus, exception words are common in Arabic (Coulmas, 2003). The consonant string is a semantic root, from which various related words can be derived through the addition of vowels. But since the short vowels are not normally represented, and the long vowels are not always represented directly or transparently, the Arabic reader usually must infer the correct word from a limited number of graphemes.

Ryan and Meara (1991) suspected that Arabic readers learning English might transfer their L1 orthographic-processing knowledge to English, which represents vowels explicitly (though not always transparently). To test this, they used a same-different task in which participants saw two consecutive stimuli. The first stimulus was always a correctly spelled, high-frequency, 10-letter word in English. The second stimulus either matched the first stimulus perfectly, or differed from it by one missing letter. That missing letter was always a vowel. Ryan and Meara reasoned that an Arabic reader might be more prone to infer missing vowels than native-English readers and ESL learners who read fully alphabetic L1 orthographies. This tendency would cause them to err more often when the stimuli did not match. This is exactly what they found. Reaction times were slower and error rates were higher for Arabic readers than for either the other ESL group or the native readers. Their conclusion was that the Arabic readers were somehow prone to encoding consonantal information over vocalic information when learning English vocabulary. This is exactly what Arabic readers must do in their L1, so the effect in English is evidence of transfer.

The studies just reviewed show evidence that L2 learners apply processing knowledge acquired in reading their L1 to reading their L2, at least in some ways. This definitely seems to be the case when the writing systems in the two languages differ in terms of linguistic representation (e.g., morphemes vs. phonemes) or in terms of depth of representation at a given level of linguistic representation (e.g., alphabets representing consonants and limited vowels vs. those that fully represent consonants and vowels).

A third possibility for orthographic transfer is between writing systems that represent the same linguistic units to the same degree, but with different symbols (e.g., Japanese vs. Cherokee syllabaries, English vs. Russian alphabets). It is not clear what sort of transfer might occur among such writing systems (if any), and I am not aware of any studies that address the possibility. I list it here only as a logical possibility.

This dissertation concerns a fourth case of transfer. Many languages share writing systems. For example, Chinese and Japanese share morphographic symbols; Russian and Mongolian share alphabetic symbols, as do Arabic and Farsi, and Italian and Hungarian. But these are clearly different languages from different families. It is likely that the symbols will encode the respective linguistic units in different ways. Even related languages that share writing symbols (e.g., Russian and Ukrainian, Swedish and German) are likely to encode linguistic information differently. The differences between English and Spanish (see Chapter 2) are a perfect example of this. It seems likely that readers of writing systems that share symbols would be vulnerable to transferring grapheme-processing knowledge from their L1 to their L2.

Healy and her colleagues have addressed transfer between languages that share an alphabet (e.g., Buck-Gengler *et al.*, 1998; Gesi Blanchard, 1998). These researchers often use letter detection in natural text. They have shown that L1 knowledge transfers positively to L2 reading, particularly when the orthographies are of the same type (e.g., alphabets) and share graphemes (e.g., roman letters). See Healy (1994) for a review, including research using a letter-detection paradigm in natural text. Gesi Blanchard (1998) found that as their English proficiency increased, native Spanish-speakers showed increasingly more F-detection errors in the word OF but not in the word IF. This difference is also characteristic of native English speakers. Gesi Blanchard suggested that this might reflect phoneme congruency between English and Spanish on the word IF (/f/) but not on the word OF (/v/). That is, the Spanish letter F never corresponds to the phoneme /v/. Such facts might lead developing Spanish-dominant bilinguals to think that the same is true in English, resulting in transfer. But interestingly, the Japanese-English bilinguals in Gesi Blanchard's study showed the same pattern. This suggests that differences between English and Spanish orthographies alone cannot account for the letter-detection errors among the Spanish-English bilinguals.

The experiments in this chapter also use letter detection to examine transfer effects between alphabets that share symbols. However, like the other experiments in this dissertation, they rely on the presentation of words one at a time, not in natural text.

English-dominant and Spanish-dominant bilingual adults did the experiment with 33-ms primes in their L2. If transfer of letter- or grapheme-processing occurs between English and Spanish, then native English readers should show no isolated double-vowel (IDV) facilitation effect in Spanish, at least not at low proficiency levels. The reverse should be true for native Spanish readers learning English as an L2. They should show an IDV facilitation effect in English, at least at lower proficiency levels. Whether these potential transfer effects persist among more proficient learners is a matter of how easy it is for them to re-associate letters with the new linguistic system, if it is possible at all.

5.2 Experiment 3A: English-dominant bilinguals – Spanish materials

5.2.1 Participants

The group of developing English-dominant bilingual adults were 33 native, English-reading adults who were learning Spanish as an L2, or who had studied it recently. All were undergraduates at the University of Arizona, and were doing the experiment for course credit.

The participants were divided into high- and low-proficiency groups using grade-equivalent scores on the Letter-Word Identification subtest of the Woodcock-Muñoz Language Survey in Spanish (WMLS-Spanish; Woodcock & Muñoz-Sandoval, 1993). The test and the grade-equivalent scores are described below under Materials. Participants with a grade-equivalent score of 4.1 or less were classified as low proficiency. Participants with a grade-equivalent score of 4.5 or higher were classified as high proficiency. This division was somewhat arbitrary, based on the overall balance of subjects, not on any particular proficiency criterion.[50]

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[50] In fact, one might conclude that scoring around a 5th-grade reading level does not indicate advanced proficiency in the language, though a 5th-grade reading level probably reflects a higher level of reading proficiency in a shallow orthography like Spanish than it does in a deep orthography like English (Seymour, Aro, & Erskine, 2003).

There were 15 participants in the low-proficiency group, and 18 in the high-proficiency group. The results of the low-proficiency group are presented first since I expected they would differ the least from monolingual English readers.

5.2.2 Procedures

The experimental materials and task were the same for this experiment as for experiment 1 (Spanish monolingual participants, Spanish experiment, 33-ms prime), except that the oral and written instructions were in the participants' dominant language, namely English. [51]

I include below only the materials and task description for the WMLS-Spanish mentioned above, since this has not yet been described.

5.2.2.1 Materials

The WMLS-Spanish battery of tests is a series of proficiency measures that were normed on native Spanish-speaking populations in various Latin American countries. But the test battery is designed to measure proficiency in nonnative speakers. The age range of the norming population was wide, spanning from school-age children to adults in their 90s. Only the Letter-Word Identification subtest was used for this dissertation.

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[51] Two laptop computers were used for all bilingual adults. One was a *Toshiba Satellite A45-S121* running on *Windows XP*, and the other was a *Dell Inspiron 3000* running on *Windows 98*. The input devices were a *Saitek P880 Pad USB* game controller and a *Microsoft SideWinder Game Pad USB*. The *Toshiba Satellite* used both input devices, and the *Dell Inspiron* was used with the *Saitek* input device only.

This subtest measures knowledge of grapheme-phoneme correspondences and vocabulary size. Various scores can be derived from the raw score, but the one relevant to this dissertation is the grade-equivalent score. A participant's grade-equivalent score is the grade level at which the participant's individual score and the average score for a subset of the norming population have the same value.[52] For example, if a participant's grade-equivalent score is 3.2, we know that children who were in grade level 3.2 had the same average score as that participant.

5.2.2.2 Task

In the Letter-Word Identification subtest, participants simply read aloud Spanish words presented to them in list form as accurately and fluently as possible. Participants receive instructions for the task in their L1, English. The list begin with simple words (e.g., DE, POR, LUZ), and they become progressively more complex (e.g., JUEVES, INTERROGAR, MUNICIPALIDAD, RESQUEBRAJADIZO). Participants are encouraged to take their time, and to practice difficult words silently to themselves first before trying to pronounce them out loud. Words pronounced correctly by the second try are marked as correct. If they are pronounced incorrectly or with major pauses they are marked as incorrect. Once a basal score of six correct is established, word lists of sequentially

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[52] The scores used to derive grade-equivalent scores were not raw scores, but rather W Scores. The W Score is a transformation of the raw score into an interval-based standardized score across the test-taking population. A value of 500 represents the average score of a beginning 5th grader. The W Score is based on the Rasch ability scale (Rasch, 1960; Wright & Stone, 1979). See Woodcock (1978) for more information on W Scores.

increasing difficulty are presented until the participant scores six incorrect in a row. The participant is always allowed to finish the page she is on, even when the ceiling has already been met. The raw score was calculated by adding all the correct responses below the ceiling to the total number of items below the basal. The corresponding grade-equivalent score was available in a table in the back of the testing manual.

5.2.3 Predictions

There are a couple of possible outcomes in the Spanish experiment with English-dominant bilingual adults. The bilinguals may transfer orthographic-processing knowledge from English to Spanish, or they may not. In either case, the low-proficiency group is unlikely to show IDV facilitation in Spanish. This is because they have had little experience with the orthography, or do not understand Spanish enough. If they do show the effect, then one would have to contend with the possibility that letter processing in written Spanish and English are completely independent phenomena.

It is more likely that the high-proficiency bilinguals will tell us something about transfer. On one hand, the high-proficiency bilinguals, even if they transferred their English alphabetic processing knowledge when they first began to learn Spanish, may have read enough in the L2 to show some IDV facilitation. If the low-proficiency group shows no such effect, but the high-proficiency group does, then I might infer that transfer occurs early but does not last. That is, with reading experience comes language-specific processing knowledge. On the other hand, if both the low- and high-proficiency groups fail to show IDV facilitation, then one might infer that alphabetic transfer is persistent from English to Spanish. In other words, it would be difficult for readers of an L1 using a given alphabetic script to learn to process that script in an L2 like native readers of the L2 do.

5.2.4 Results

The same rejection, cutoff, and trimming procedures as in experiment 1 (p. 101) were applied to the data in this experiment. The data from participants with error rates above 20% were not included in the analyses. There was only one such subject, who would have been included among the high-proficiency bilinguals. All reaction times below 200 ms or above 1,000 ms were deleted. And for each participant, reaction times were trimmed to ± 2SD from that participant's mean.

5.2.4.1 Low-proficiency group

The mean reaction times for the low-proficiency group can be seen below in Figure 13. Mean errors, reaction times, facilitation, and benefit can be seen in Table 19.

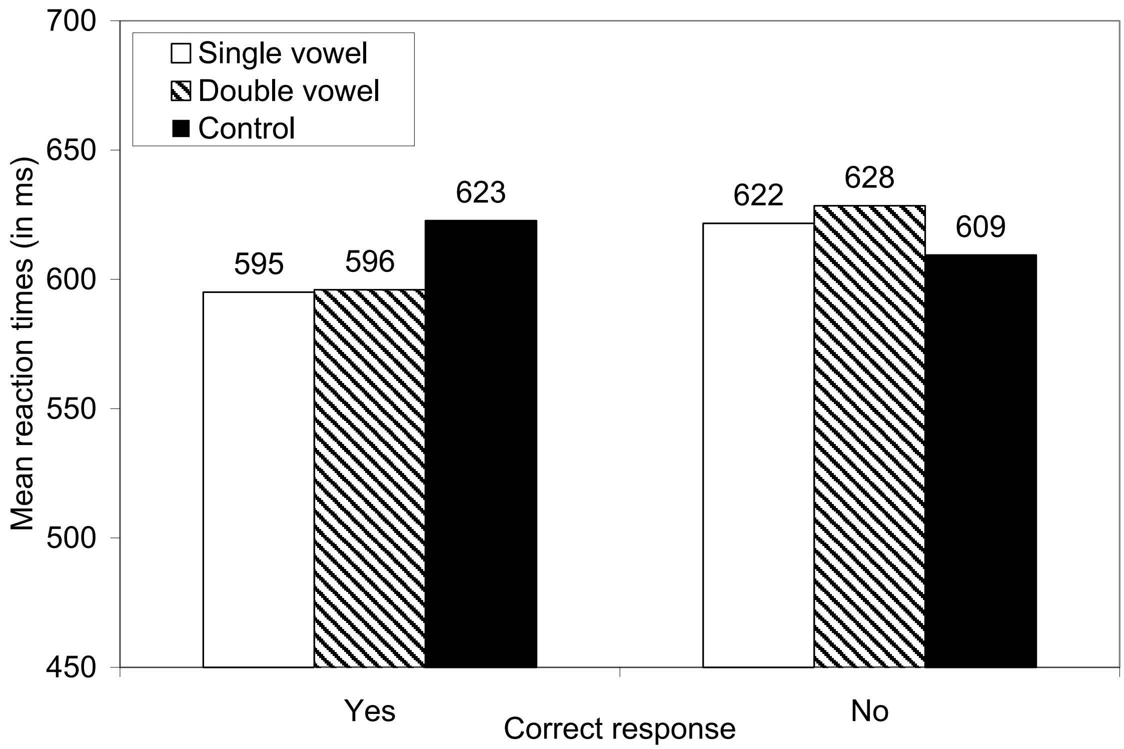

FIGURE 13. Mean reaction times (in ms) for English-dominant bilingual adults with low proficiency in Spanish (N=15) on Spanish materials.

In the analysis of reaction times, a 2x3 factorial ANOVA (Response x Prime Type) showed a main effect for response, but only in the analysis by item, $F_1(1,12) = 2.11$, $p < .2$, $F_2(1,29) = 5.03$, $p < .035$. There was no main effect for prime type in either analysis. However, the interaction between response and prime type was significant in both analyses, $F_1(2,24) = 7.05$, $p < .004$, $F_2(2,58) = 4.07$, $p = .025$.

Planned comparisons showed significant differences in the YES responses. The 28-ms facilitation for the single-vowel primes was significant by participant and item. The 27-ms facilitation for the double-vowel primes was significant only by participant.

There were no other significant differences. The closest was the 19-ms inhibition for the double-vowel primes in the NO responses, which was marginal by item. In the analysis of error rates, a 2x3 factorial ANOVA (Response x Prime Type) showed no effects.

TABLE 19. Mean Error Rates, Reaction Times (RT), Facilitation, and Benefit for English-dominant Bilingual Adults with Low Proficiency in Spanish (N=15) on Spanish Materials with 33-ms Primes as a Function of Response and Prime Type.

	Dependent measures			
Response and vowel prime type	Error rate (%)	RT (ms)	Facilitation (ms)	Benefit (ms)
YES				
Single	1.7 (3.5)	595 (116)	28*	1
I→*virrey*→*HINCAR*				
Double	5.6 (8.7)	596 (120)	27[P]	
I→*siervo*→*HINCAR*				
Control	5.0 (5.3)	623 (121)		
I→*lustre*→*HINCAR*				
NO				
Single	3.4 (5.3)	622 (107)	-13	6
I→*virrey*→*CONEJO*				
Double	3.9 (7.7)	628 (100)	-19	
I→*siervo*→*CONEJO*				
Control	2.8 (5.2)	609 (102)		
I→*lustre*→*CONEJO*				

Note. Facilitation = [Control]-[Single] and [Control]-[Double]. Benefit = [Double]-[Single]. SD in parentheses.
* Significant by participant and item
[P] Significant by participant

5.2.4.2 High-proficiency group

The mean reaction times for the high-proficiency group can be seen below in Figure 14. Mean errors, reaction times, facilitation, and benefit can be seen in Table 20.

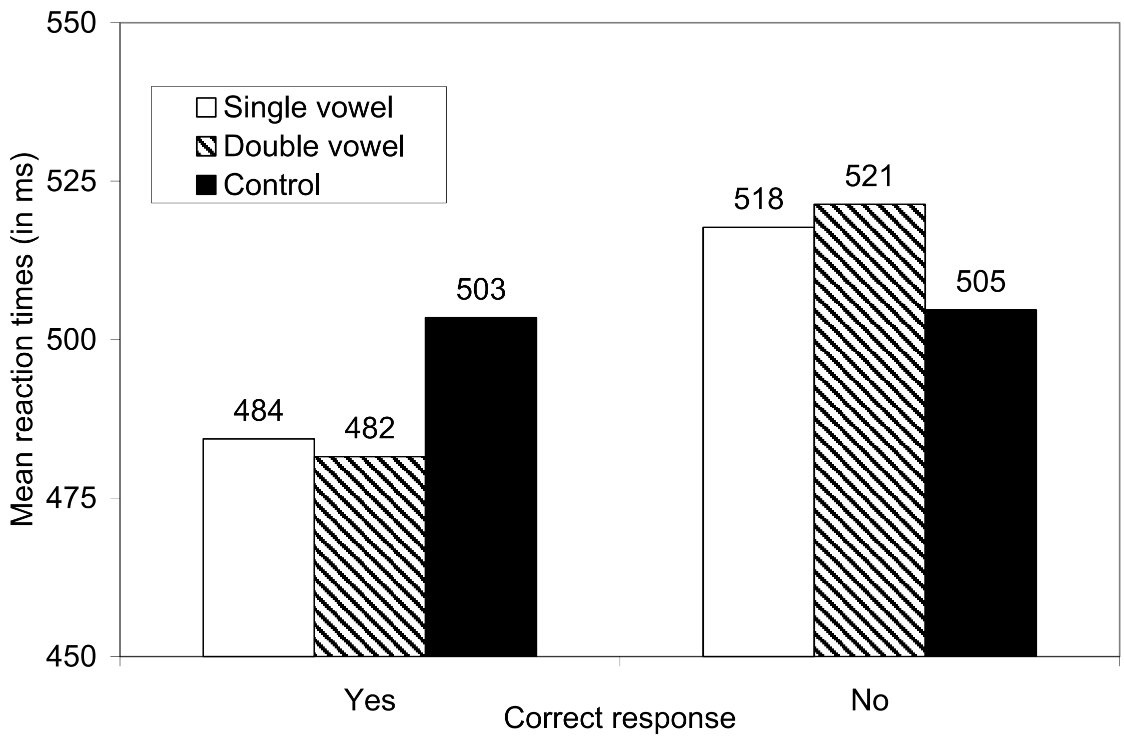

FIGURE 14. Mean reaction times (in ms) for English-dominant bilingual adults with high proficiency in Spanish (N=18) on Spanish materials.

In the analysis of reaction times, a 2x3 factorial ANOVA (Response x Prime Type) showed a main effect for response, which was significant in both the analyses by participant and by item, $F_1(1,15) = 14.87$, $p < .002$, $F_2(1,29) = 18.24$, $p < .0002$. There was no main effect for prime type, $F_1 < 1$, $F_2 < 1$. However, the interaction between response and prime type was significant, $F_1(2,30) = 7.64$, $p < .003$, $F_2(2,58) = 7.62$, $p = .002$.

Planned comparisons showed significant differences in the YES responses. The 19-ms facilitation for the single-vowel primes was marginal by participant and significant by item. The 21-ms facilitation for the double-vowel primes was significant by participant and item. No other differences were significant.

In the NO responses, the 13-ms inhibition for the single-vowel primes was not significant in either analysis. The 16-ms inhibition for the double-vowel primes was significant in both analyses. No other differences were significant.

In the analysis of error rates, a 2x3 factorial ANOVA (Response x Prime Type) showed a main effect for response, but this was only marginal in the item analysis, $F_1(1,15) = 8.64$, $p < .011$, $F_2(1,30) = 3.41$, $p < .08$. There were no other main effects or interactions.

TABLE 20. Mean Error Rates, Reaction Times (RT), Facilitation, and Benefit for English-dominant Bilingual Adults with High Proficiency in Spanish (N=18) on Spanish Materials as a Function of Response and Prime Type.

	Dependent measures					
Response and vowel prime type	Error rate (%)		RT (ms)		Facilitation (ms)	Benefit (ms)
YES						
Single	6.0	(6.3)	484	(88)	19[I]	-2
I→*virrey*→*HINCAR*						
Double	9.3	(8.5)	482	(82)	21*	
I→*siervo*→*HINCAR*						
Control	5.6	(7.0)	503	(70)		
I→*lustre*→*HINCAR*						
NO						
Single	3.8	(5.4)	518	(76)	-13	3
I→*virrey*→*CONEJO*						
Double	3.8	(5.4)	521	(75)	-16*	
I→*siervo*→*CONEJO*						
Control	3.3	(5.1)	505	(72)		
I→*lustre*→*CONEJO*						

Note. Facilitation = [Control]-[Single] and [Control]-[Double]. Benefit = [Double]-[Single]. SD in parentheses.
* Significant by participant and item
[I] Significant by participant (F_2)

5.2.5 Discussion

The experiment seems to have worked with both groups of English-dominant bilinguals. Although the number of participants in these groups was smaller than in experiments 1 through 2D, the expected congruency effects still surfaced.

The low-proficiency group was slower overall than the high-proficiency group. This difference could reflect any of several anomalous differences between participant groups (e.g., enthusiasm for the task, baseline reaction speeds), but it is not clear that the overall reaction times say much about behavior within each group. Both groups responded relatively faster to targets in YES responses when the targets were preceded by congruent primes, and faster to targets in NO responses when the targets were preceded by incongruent primes. Crucially, neither group seems to show much of a trend towards single-vowel benefits or detriments.

The statistics bear out these descriptions of the data. The congruency effects were a little clearer for the high-proficiency group (e.g., in the NO responses), but this could have been due to increased power because of the slightly higher number of participants in that group. Overall, it seems that the native English readers transfer the way they process English orthography to Spanish (at least at the level of letters and graphemes), and have a difficult time acquiring the processing knowledge used by native Spanish readers.

It remains to be seen whether Spanish-dominant bilinguals transfer their alphabetic processing knowledge to English. This is the focus of the next two experiments.

5.3 Experiment 3B: Spanish-dominant bilinguals – English materials

5.3.1 Participants

The group of developing Spanish-dominant bilingual adults consisted of 27 native, Spanish-reading adults who began learning English after the age of 14. These participants were drawn from several populations. Several of them were contacted in Argentina through family and friends. They had all had some experience learning English recently. Some others were learning English as an L2 in an ESL program at the University of Arizona. Still others were graduate students at the University of Arizona. The first two groups tended to be of lower proficiency in English, and the last one tended to be of higher proficiency.

Together, the group was divided into high and low English-proficiency levels based on the Letter-word Identification subtest of the Woodcock-Muñoz Language Survey in English (WMLS-English).

5.3.2 Procedures

The materials and task for the masked-priming experiment were the same for this experiment as for experiment 2A (English monolingual participants, English experiment, 33-ms prime), except that the instructions were in the participants' dominant language, Spanish. The only other difference in this experiment was the fact that the test used to divide groups into high- and low-proficiency groups was slightly different than in the experiment with the English-dominant bilinguals in Section 5.2 above. These differences are noted below.

5.3.2.1 Materials

The WMLS-English was given in exactly the same way to the Spanish-dominant participants as the WMLS-Spanish was given to the English-dominant participants. The only differences in procedure were that the test was in English and the instructions were given in Spanish. See Section 5.2.2.1 for a description of how the WMLS-Spanish was given in English to the English-dominant bilinguals.

The WMLS-English was normed on several populations geographically scattered throughout the United States. That is the main difference between this test and the WMLS-Spanish besides language. Importantly, the Letter-Word Identification subtest of the WMLS-English is not a translation of the same task in the WMLS-Spanish, or vice-versa. Each subtest contains a unique set of items designed to measure proficiency in the language. Otherwise, there are no major differences.

5.3.3 Predictions

As in the experiments on English-dominant bilingual adults, there are a few possible outcomes in the English masked-priming experiment with Spanish-dominant bilingual adults. The low-proficiency group is more likely to show IDV facilitation in English. They have too little experience with the English alphabet, or too little proficiency in the language. They should use their L1 alphabetic processing knowledge.

If they do not show the effect, then there are two possible interpretations. First, the IDV facilitation effect in experiment 1 was a Type I error. Second, Spanish-dominant learners of English acquire native-like alphabetic processing knowledge very early on.

But it is more likely that the high-proficiency bilinguals will reveal more about transfer. Even if they transferred their L1 alphabetic processing knowledge when they first began to learn English, may have had enough experience reading English to reduce or eliminate IDV facilitation. That is, they may show equal facilitation with single- and double-vowel primes. If the low-proficiency group shows IDV facilitation, but the high-proficiency group does not, then we can infer that transfer occurs early but does not last. But if both the low- and high-proficiency groups show IDV facilitation in English, then alphabetic transfer may be persistent.

5.3.4 Results

The same rejection, cutoff, and trimming procedures as in experiment 1 (p. 101) were applied to the data in this experiment. The data from participants with error rates above 20% were not included in the analyses (but no participant in these two groups had such a high error rate). All reaction times below 200 ms or above 1,000 ms were deleted. And for each participant, reaction times were trimmed to ± 2SD from that participant's mean.

5.3.4.1 Low-proficiency group

The resulting mean reaction times for the low-proficiency group can be seen in Figure 15. Mean errors, reaction times, facilitation, and benefit can be seen in Table 21.

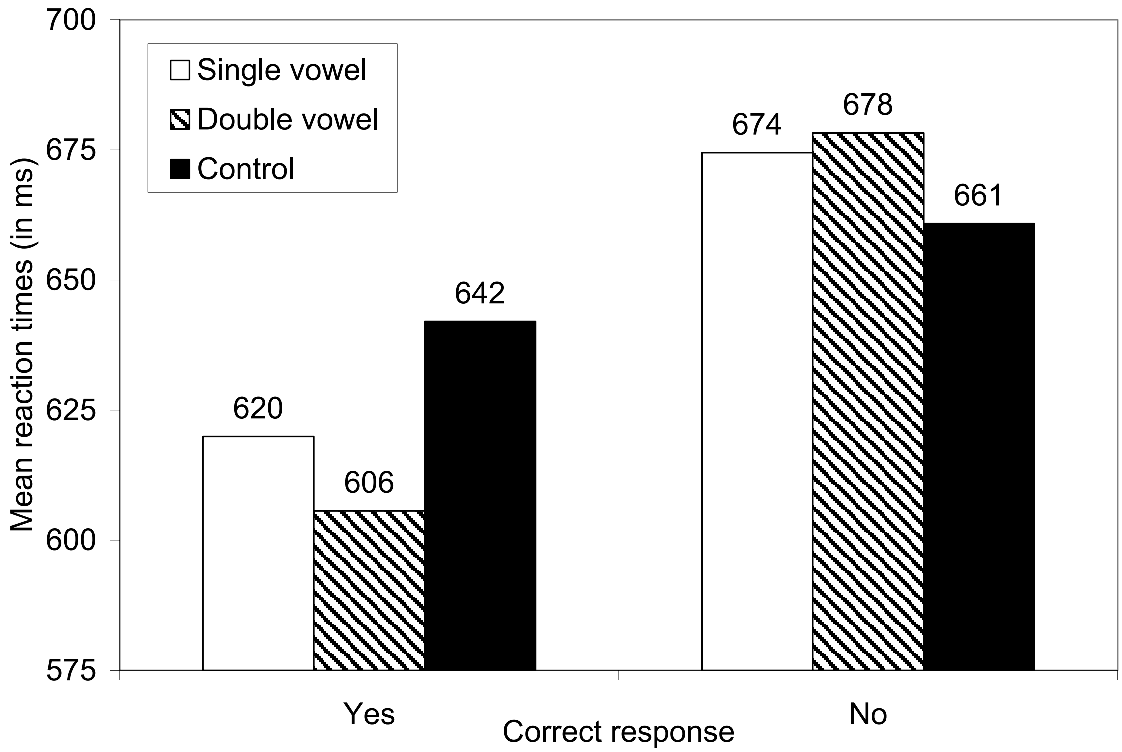

FIGURE 15. Mean reaction times (in ms) for Spanish-dominant bilingual adults with low proficiency in English (N=15) on English materials.

In the analysis of reaction times, a 2x3 factorial ANOVA (Response x Prime Type) showed a main effect for response, which was significant in both the analyses by participant and by item, $F_1(1,12) = 33.11$, $p < .0001$, $F_2(1,30) = 41.27$, $p < .0001$. There was no main effect for prime type in either analysis. But the interaction between response and prime type was significant, $F_1(2,24) = 9.48$, $p < .001$, $F_2(2,60) = 5.01$, $p < .001$.

The same ANOVA on error rates, showed an significant interaction between response and prime type by participant, $F_1(2,24) = 5.83$, $p < .009$, $F_2(2,60) = 1.76$, $p < .2$.

TABLE 21. Mean Error Rates, Reaction Times (RT), Facilitation, and Benefit for Spanish-dominant Bilingual Adults with Low Proficiency in English (N=15) on English Materials as a Function of Response and Prime Type.

Response and vowel prime type	Dependent measures: Error rate (%)		Dependent measures: RT (ms)		Facilitation (ms)	Benefit (ms)
YES						
Single	3.9	(5.3)	620	(90)	22^{P}	-14
E→crest→SPECK						
Double	5.0	(6.1)	606	(90)	36*	
E→field→SPECK						
Control	5.6	(6.8)	642	(102)		
E→block→SPECK						
NO						
Single	10.1	(7.9)	674	(87)	-13	4
E→crest→STAMP						
Double	4.0	(6.5)	678	(95)	-17	
E→field→STAMP						
Control	3.4	(6.4)	661	(90)		
E→block→STAMP						

Note. Facilitation = [Control]-[Single] and [Control]-[Double]. Benefit = [Double]-[Single]. SD in parentheses.
* Significant by participant and by item
^{P} Significant by participant

Planned comparisons showed significant differences in the YES responses. The 22-ms facilitation for the single-vowel primes was significant by participant only. The 36-ms facilitation for the double-vowel primes was significant by both participant and item. The 14-ms single-vowel detriment was not significant in either analysis. All comparisons for the NO responses were not significant.

5.3.4.2 High-proficiency group

The mean reaction times for the high-proficiency group can be seen in Figure 16 Mean errors, reaction times, facilitation, and benefit can be seen in Table 22.

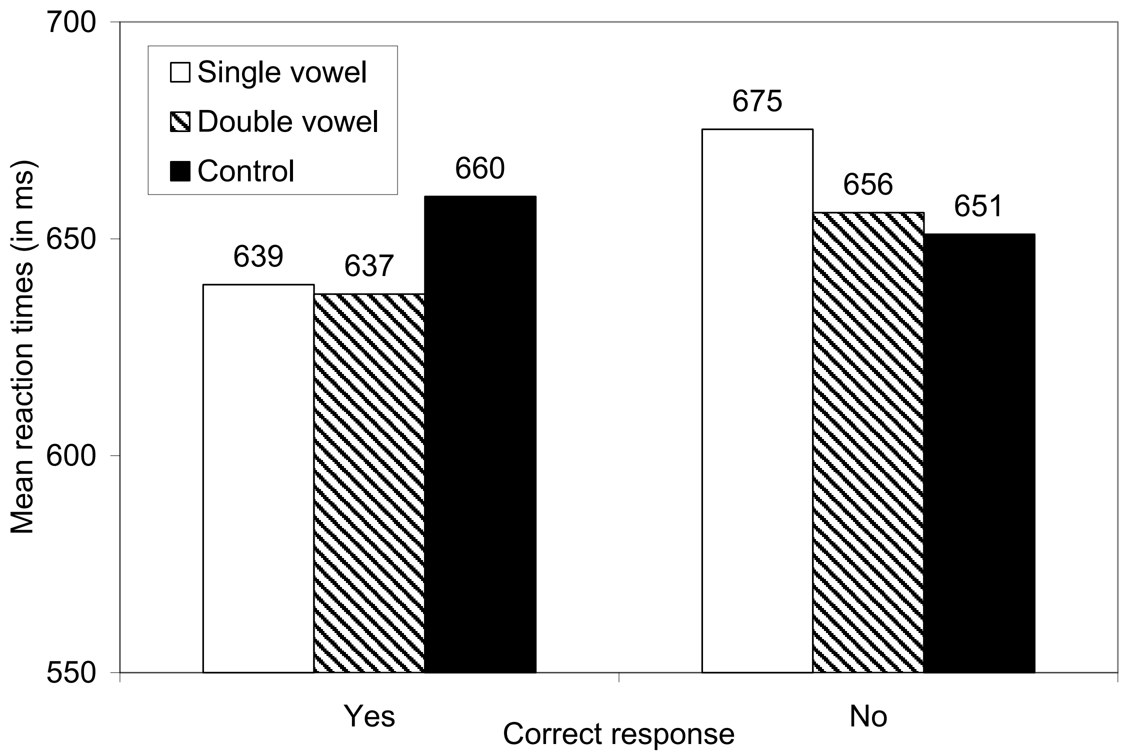

FIGURE 16. Mean reaction times (in ms) for Spanish-dominant bilingual adults with high proficiency in English (N=12) on English materials.

In the analysis of reaction times, a 2x3 factorial ANOVA (Response x Prime Type) showed a main effect for response, but it was only significant by item, $F_1(1,9) = 2.45$, p $< .16$, $F_2(1,30) = 9.68$, $p < .004$. There was no main effect for prime type. There was only a marginal interaction between response and prime type in the analysis by participant. It was not significant by item, $F_1(2,18) = 3.24$, p $< .065$, $F_2(2,60) = 0.23$, $p < .8$. In the analysis of error rates, a 2x3 factorial ANOVA (Response x Prime Type) showed no main effects or interactions.

Interestingly, there was a significant three-way interaction of file by response by prime type. This was only significant in the analysis by item, $F_1(4,18) = 2.01$, $p < .14$, $F_2(4,60) = 4.97$, $p < .002$. This suggests that there may have been something unusual about one of the participant groups in one of the files. They may have responded very differently from the participants in the other files. Since the high-proficiency group was small (N = 12), and there were only 4 participants for each of the 3 files, the probability of this sort of anomaly is higher. Closer inspection revealed a clear difference in the files. On one of the files, participants tended, in the YES responses, to respond faster after control primes than after either single- or double-vowel primes. This was the opposite of what happened in the other two files. This anomaly may account for the lack of significant effects here, even though the response-congruency trends are in the expected direction and of the same general magnitude found in the experiments thus far. To rectify this situation, it would be necessary to find more participants.

TABLE 22. Mean Error Rates, Reaction Times (RT), Facilitation, and Benefit for Spanish-dominant Bilingual Adults with High Proficiency in English (N=12) on English Materials as a Function of Response and Prime Type.

	Dependent measures					
Response and vowel prime type	Error rate (%)		RT (ms)		Facilitation (ms)	Benefit (ms)
YES						
Single	2.8	(5.4)	639	(153)	21	-2
E→crest→SPECK						
Double	6.3	(5.2)	637	(148)	23	
E→field→SPECK						
Control	2.8	(4.1)	660	(138)		
E→block→SPECK						
NO						
Single	4.9	(5.6)	675	(121)	-24	-19
E→crest→STAMP						
Double	4.2	(5.7)	656	(112)	-5	
E→field→STAMP						
Control	2.1	(3.9)	651	(125)		
E→block→STAMP						

Note. Facilitation = [Control]-[Single] and [Control]-[Double]. Benefit = [Double]-[Single]. SD in parentheses.

5.3.5 Discussion

Unfortunately, the results with the high-proficiency group were inconclusive. But the data from the low-proficiency group may be of interest.

The results from the Spanish-dominant bilinguals with relatively low-proficiency in English look very similar to the results from the Spanish monolingual adults in experiment 1 (Section 4.1). In that experiment, the IDV facilitation effect was significant by both participant and item, but single-vowel facilitation was marginal, and only in the analysis by participant (see Section 4.1.3). In the experiment with Spanish-dominant bilinguals with low proficiency in English, the only differences were that single-vowel facilitation was a little stronger statistically (significant vs. marginal by participant) and in magnitude (22 vs. 15 ms). This leads me to suspect that the Spanish-dominant bilinguals with low proficiency in English, like their English counterparts, are transferring orthographic-processing knowledge of the L1 to their L2.

As just noted, however, the anomaly with the high-proficiency group makes it impossible to determine whether this trend persists throughout proficiency levels. It seemed to persist among the English-dominant bilinguals, but Spanish-English transfer may operate differently. Determining this will have to be reserved for future studies.

5.4 Summary

I will now summarize the basic findings in this chapter. Two main participant groups did the letter-detection experiments with 33-ms masked primes. One group was English-dominant bilinguals learning Spanish. This group was divided into two, based on their Spanish proficiency (high vs. low). The second group was Spanish-dominant bilinguals learning English. This group was also divided into high and low English-proficiency groups.

A strong expectation was that the low-proficiency groups would show evidence of transferring the alphabetic processing knowledge they acquired in their L1 to their L2. This should always be the case. That is, if there are cross-alphabetic processing differences in the first place, learners should take with them what they know, which can only be L1 knowledge in the case of low-proficiency L2 learners.

The results of the experiments with both low-proficiency groups seems to confirm this. First, the English-dominant group with low proficiency in Spanish showed English-like effects in the Spanish experiment. That is, the facilitation in the YES responses from congruent primes was of about equal magnitude (though only double-vowel primes were significantly different from controls by both participant and item). The inhibitory trends from those prime types were of about equal magnitude (compared to each other), though the inhibition was not significant in either case. These results are much like those found in experiment 2A with English monolingual adults (see Section 4.2).

One important difference, however, is that the significant congruency effects occurred in the NO responses in that experiment, whereas they appeared in the YES responses in this experiment. A possible explanation here is that the bilinguals took more time in making their YES responses. The mean reaction time for the English-dominant bilinguals over all the YES responses was 605 ms (SD = 117). In contrast, the same mean response time for the English monolingual adults at 33 ms was 499 ms (SD = 81). This is over 100 ms faster. Perhaps the bilingual group did not have the bias to respond YES that the monolingual group was argued to have. This may have given the bilingual group enough time to process the information in the primes when the answer was YES.

Second, the Spanish-dominant group with low proficiency in English paralleled the results with the English dominant group with low proficiency in Spanish. That is, they showed Spanish-like effects when doing the task in English. Double-vowel facilitation in YES responses was significant, whereas single-vowel facilitation in YES responses was smaller in magnitude and not so clearly significant. These results are very similar too the results in experiment 1 with Spanish monolinguals. It is likely then, that low-proficiency L2 learners transfer at least some alphabetic processing knowledge from their L1.

In contrast to the strong expectation that low-proficiency bilinguals would transfer alphabetic processing knowledge from their L1, it was less clear how more proficient bilinguals would do. If they showed the same pattern as monolinguals in their L1 (like the low-proficiency bilinguals did), then I could conclude that transfer of alphabetic processing knowledge persists even as bilinguals become more proficient in their L2. On the other hand, if the more proficient bilinguals started showing the pattern that monolinguals of the L2 showed, I could conclude that transfer of alphabetic processing knowledge is only temporary, and that learners eventually adjust to their new alphabet.

The implications here are clearer with the highly proficient English-dominant bilinguals than with the highly proficient Spanish-dominant bilinguals. The highly proficient English-dominant bilinguals showed essentially an English-like pattern when doing the task in Spanish. This suggests that it is difficult for L2 learners to acquire native-like alphabetic processing knowledge in their L2. It is worth noting, however, that the participants that made up the English-dominant bilingual groups were drawn from a pool of undergraduates who were either studying Spanish at the time, or had done so in the recent past. I separated them into high- and low proficiency groups, but this division was arbitrary, and may not have resulted in meaningful proficiency levels. In fact, the English-dominant high-proficiency group may well have been of lower proficiency in some sense.

In the experiment with Spanish-dominant bilinguals with high proficiency, there were no significant effects, so there is little to discuss. The trend in the data seems to support the idea that language learners can learn to process the alphabet of their L2 like monolinguals of the L2. This suspicion is made more plausible by the fact that this group had much higher L2 proficiency than the English-dominant high-proficiency bilingual group. Recall that the Spanish-dominant group was drawn, for the most part, from a pool of students doing graduate work in English at an American university, whereas the English-dominant group was drawn from undergraduate students who also happened to be studying Spanish (or who had done so until recently). If either group were to show effects in their L2 like monolinguals of that language, the more likely group would be the higher proficiency Spanish-dominant bilinguals. But confirmation of this trend will also have to wait until future studies.

It seems then that alphabetic transfer does take place between languages that use identical alphabetic characters, and that this transfer persists to some degree. However, it is unclear how long it persists. It may disappear altogether at very high levels of proficiency. The answer to this question may emerge in future studies.

CHAPTER 6 STUDY OF CHILDREN

This chapter covers the portion of this investigation carried out with children. The first part of the current chapter pursues the same questions addressed in the last, but with bilingual children. The second part of the current chapter addresses the fourth question brought up at the beginning of the dissertation: Namely, at what age do congruency effects begin to emerge? I begin with the bilingual children.

There are several differences that make testing bilingual children interesting. Most agree that in contrast to children, adults are usually poor L2 learners (Bialystok & Hakuta, 1994; Birdsong, 1999; Hylentstam & Abrahamsson, 2003; Johnson & Newport, 1989; Lenneberg, 1967; Newport, 1990). Also, proficient adult readers have been exposed to print for many years, whereas young readers have been exposed to it for a relatively short time. These different age and exposure characteristics make it interesting to compare the adult and child bilingual groups on the nature and degree of alphabetic transfer. For instance, does language-learning potential (youth in this case) help determine how well and quickly L2 grapheme-phoneme correspondences (GPCs) formed? Or does more exposure to an L1 orthography make persistent L1-L2 transfer more likely? It could if L1 GPCs solidify over time and inhibit the formation of L2 GPCs. If either or both these possibilities are true, then I would expect transfer effects to be greater among adults than among children.

6.1 Experiment 4A: Spanish-dominant bilingual children – English materials

6.1.1 Participants

The Spanish-dominant bilingual children in this study come from a unique school in Argentina in which English instruction is taken very seriously. There were important reasons for going to a Spanish-speaking country to test this populations. There are many Spanish-dominant bilingual children in southern Arizona. However, L1 literacy and competence for native Spanish-speaking children is not systematically promoted in Arizona.[53] Nor is it generally in the rest of the US. Where Spanish literacy is promoted, it is usually only done to facilitate literacy in English. Once literacy in English emerges in these children, the school system ceases to develop literacy in Spanish. Mainstreaming L2 learners into English-only classrooms is the standard goal of transitional bilingual education (Bialystok, 2001; Brisk, 1998).

The uncertain status of Spanish literacy for native speaking children in Arizona's educational system would weaken any conclusions I might draw about the role of alphabetic transfer from Spanish to English. That is, it would be difficult to state with confidence that they were transferring knowledge from their L1 to their L2 orthography if their L1 orthographic knowledge was under-developed in any way.

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[53] In fact, with the passage of Proposition 203 in the year 2000, the Arizona public-education system is now forced to limit even further native Spanish children's access to academic development in their native language. Such children, who used to glean at least a minimal degree of academic competence in Spanish through transitional bilingual education, can no longer routinely access content instruction in their own language, except in cases of widespread parental request or very low English competence.

As a result, I collected data from students at a private school in Rosario, Argentina. The language profile of these participants is tied up with the nature of the school they attended. So I will describe their school. In this highly regarded bilingual school, teachers spoke only English during afternoon classes even though the vast majority of them were native Spanish speakers. The English proficiency of the faculty was, in fact, extremely high. All of the teachers regularly attended language-teaching workshops in Argentina, were well informed about language pedagogy, and were encouraged by the school's headmistress to be innovative in class. It is also worthwhile to note that in Argentina, English learning is highly regarded. It is perceived as a door to good employment opportunities and economic success (Friedrich, 2002).

Students in this school start learning English at age 3. In preschool through kindergarten, they attend classes only in the morning, which is divided into two equal periods of English and Spanish, in that order. After kindergarten, English classes move to the afternoon. Here, classes focus on reading, writing, speaking, and listening. But they also integrate, where possible, content taught in the morning in Spanish. This makes the English instruction scaffolded where possible (van Lier, 1996). This format of instruction for English lasts until the students graduate from high school.

The children were selected from grades 5-8 and had been learning English for several years. These grades were selected to ensure that the children were able to perform on an English-language task with some degree of proficiency. It would have been no use to test children with very low levels of competence in English. Also, they were literate in

Spanish, and had become literate in Spanish before they started to read in English. This is important if it is going to be possible to make any claims at all about alphabetic processing transfer. The 111 students who participated in the study were 64 girls and 47 boys. There were 31 in the 5th grade, 28 in the 6th grade, 24 in the 7th grade, and 28 in the 8th grade. The mean age was 11;10.

The data of 48 participants were excluded from the analysis. There were several reasons. Some participants had been raised speaking some English at home. Since it is not clear what effect this would have on the experiment, these 19 participants' data were removed from the analyses. One participant's data were not included because she chose not to finish the letter-detection task.[54] Another participant's data could not be included because a computer glitch prevented the data from being written to the file. Two participants' data were excluded because they had error rates greater than 20%. Three of the participants' data were not included because their parents indicated that the child had a learning disability of some sort. Finally, 22 more participants' data were randomly deleted in order to balance the *n* in the three files of the experiment. There was nothing unusual about the other participants' language or learning backgrounds. Overall, this left 63 participants' data for analysis.

The main group was divided into proficiency levels according to grade-equivalent scores on the Letter-Word Identification subtest of the WMLS-English (see Section

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[54] This participant was reassured that her decision had no bearing on her grades, then thanked for being willing to come and try the task out, then finally brought back to class.

5.2.2.1). The division was arbitrary. Those scoring at or below 3.7 were classified as low proficiency. Those scoring above 3.7 were classified as high proficiency.

In the low-proficiency group, there were 17 girls and 10 boys, for a total of 27 participants. There were 5 fifth graders, 7 sixth graders, 4 seventh graders, and 8 eighth graders. The mean age was 11;10. In the high-proficiency group, there were 21 girls and 15 boys for a total of 36 participants. There were 7 fifth graders, 5 sixth graders, 10 seventh graders, and 14 eighth graders. The mean age was 12;3.

6.1.2 Procedures

The basic experimental design for the children was similar to that of the adults, with a few important differences. For one, the materials consisted of higher-frequency words more suitable to young readers. This was to give them confidence since the task does not require word identification. Another important difference had to do with the task, which was adjusted in several ways to make it more appropriate for children. These differences in materials and task are addressed below.

6.1.2.1 Materials

Item statistics are represented in Table 23 for targets, and in Table 24 for primes. The complete set of items by condition for the experiment can be found in Appendix H (p. 248).

First, I will discuss targets. This set of items included not only 5-letter monosyllabic words (e.g., DRINK) and disyllabic words (e.g., WAGON), but also six-letter mono-, di- and tri-syllabic words (e.g., STRONG, EFFECT, ORIGIN, respectively). Among the targets, there were 41 five-letter words, and 31 six-letter words. Also, there were 24 monosyllabic, 45 disyllabic, and three tri-syllabic targets. The mean number of syllables for all targets was 1.71 (SD = 0.54). In the YES responses, this was 1.69 (SD = 0.47), and in the NO responses, 1.72 (SD = 0.61). Targets and primes were matched by number of letters, but not number of syllables.

Word frequencies were determined using Kučera & Francis (1967). The targets were all high frequency. This was done so that the children had a higher chance of recognizing the words, minimizing any frustration or distraction they might experience during the task. The overall mean frequency was 83.56 per million (SD = 72.64). In the YES responses, the mean was 95.50 (SD = 91.46). In the NO responses, the mean was 71.61 (SD = 45.24).

TABLE 23. Item Statistics (Counts and Mean Frequencies) for Targets, Child Materials.

	Syllables			Letters		
N	One	Two	Three	Five	Six	Mean frequency
72	24	45	3	41	31	83.56 (72.64)

Note. SD in parentheses.

Next, I will discuss primes. Item statistics for primes can be seen in Table 24. Among the double-vowel primes, the search letter sometimes appeared as the left member of the double-vowel prime. It appeared on the left in 48% of the cases, and on the right in 52% of the cases. In the YES responses, these percentages were 47% and 53 %, respectively. In the NO responses, they were 49% and 51 %, respectively.

As noted above, primes and targets varied from one to three syllables in length. The average number of syllables for all primes was 1.59 syllables (SD = 0.57). For the single-vowel primes, the average number was 1.71 (SD = 0.57). For the double-vowel primes, it was 1.40 (SD = 0.49). And for the control primes, it was 1.67 (SD = 0.61).

All primes were high frequency. The mean frequency for all primes was 83.51 per million (SD = 72.19). For the YES responses, the mean frequency was 80.24 (SD = 55.36), and for the NO responses, it was 90.37 (SD = 85.76). The mean frequency for single-vowel primes was 77.92 (SD = 58.04). For double-vowel primes, it was 81.45 (SD = 57.89). And for control primes it was 96.46 (SD = 94.15).

TABLE 24. Item Statistics (Counts and Mean Frequencies) for Primes, Child Materials.

Vowel prime type	Syllables			Position of search letter in double vowel		Mean frequency
	One	Two	Three	Left	Right	
Single n=72	25	43	4			77.92 (58.04)
Double[a] n=71	43	28	0	34	37	81.97 (58.19)
Control n=72	29	38	5			96.46 (94.15)
Total	97	109	9			85.47 (72.32)

Note. SD in parentheses.
[a] One single-vowel prime was mistakenly included as a double-vowel prime. This item as removed from the analysis.

Finally, I will discuss the allocation of items in the six conditions of the experiment. This breakdown can be seen in Table 25 below. There were 36 target words for each of the YES and NO responses (72 total), and 18 items total for every search letter: nine YES and nine NO for A, E, I, and U, respectively. This also means that there were six single-vowel primes (three YES, three NO), six double-vowel primes (three YES, three NO), and six control primes (three YES, three NO) for each search letter. Multiplied by the number of search letters (four), there were 12 primes for each response by prime type.

TABLE 25. Allocation of Items by Condition and Search Letter in Child Experiments.

Condition		Search letter				
Response	Vowel prime type	A	E	I	U	Total
YES	Single	3	3	3	3	12
	Double	3	3	3	3	12
	Control	3	3	3	3	12
NO	Single	3	3	3	3	12
	Double	3	3	3	3	12
	Control	3	3	3	3	12
	Total	18	18	18	18	**72**

As with the adult experiments, counterbalancing served to cancel out confounding effects that might have arisen because of characteristics of the target words alone. Each prime type preceded every individual target via three different files, which were in turn randomly assigned to participants in equal numbers.

The participants were also given the Letter-Word Identification subtest of the WMLS-English. The materials did not differ from what has already been described. There were differences in the way it was administered, however, and those differences are covered in the next section.

6.1.2.2 Task

The task that the children performed was similar to that of the adults. However, instructions differed a great deal since children, at least initially, cannot be expected to understand easily the demands of a psycholinguistic task such as this. There were several other differences in the presentation of the materials during the course of the experiment, which I will outline after discussing the instructions. A script of the instructions in English and Spanish is presented in Appendix I (p. 249). There were also two test-givers, both bilingual in English and Spanish, and both of whom had practiced giving the test extensively together beforehand in order to ensure that they were giving the test in the same way.

In order to familiarize the participants with the test givers and the tasks, my co-tester and I visited each classroom to recruit participants personally. During this visit, we introduced ourselves, told the children what they would be doing in the experiment, how long it would take, and that their participation was completely voluntary and would not affect their grades. We then waited for the children to return consent forms from their parents, along with assent forms they themselves signed. We tested each of these children, one by one, according to a schedule arranged by the teachers and a liaison we hired who was familiar with the workings of the school. The liaison also allowed us to finish testing such a large group in the short time we had available.

When the participants arrived at the testing location with the liaison (usually two at a time), each of the test givers took one of the participants and began a short conversation with him or her intended to make sure they remembered who we were, to ensure that they understood why they were taken out of class, and to verify with reasonable certainty that they were comfortable being there with us. If not, we cancelled the testing session with that participant. During this conversation, we also reviewed the two tasks. At the end, we asked once again for the participant's assent. All the students in this group, with one exception, were willing to participate.

The experiment was carried out on the second floor of the school library. The second floor was off limits to other students during testing. The participants faced the back wall where they could not see any activity in the rest of the library. The test giver sat to the participant's left.

The first task my co-tester and I gave the participants was the WMLS-English. This task is straightforward for children this age, so the instructions did not differ in any significant way from the instructions to the adult Spanish-dominant bilinguals, outlined in the previous chapter.

After the WMLS-English, we oriented the participant to the masked-priming experiment. Each participant completed a combined pre-test/familiarization-task, and a set of practice items before the experiment began. The purpose of the pre-test/familiarization-task was to ensure that the participant was qualified to perform the task with no frustration, and to familiarize him slowly to the demands of the task so that by the time he started on the experimental items on the computer, he was quite sure what he was doing.

Each test-giver began the pre-test/familiarization task by presenting to the participant five small, rectangular cards, printed on both sides. On one side was an uppercase letter. It was either A, or E, or I, or U, as in the experiment. The participant was asked to look at the letter and remember what it was, but not to say it out loud. The test giver then told the participant that after the card was flipped over, he would see a word in uppercase letters. He was asked to say "yes" if the letter on the other side of the card was in the word, and "no" if it was not. Then the task began. If the participant got four out of five of these correct, he moved on to the next phase of the task. If he got fewer than that, there was a plan to move him on to another phase of the task in simplified form. But all the participants passed the pre-test/familiarization-task quite easily.

In the next phase of the task, the test giver explained to the participant how he would be doing almost exactly the same task on a computer by responding with buttons on a game controller. He was then shown the game controller and told how it worked if he was not already familiar with it.

The laptop computer was placed within normal working distance of the participant.[55] The test giver then asked the participant if he could see the screen effectively, and adjusted it accordingly. The test giver then showed the participant, screen by screen, what he would be seeing with the exception of the prime, and what he should do at each point.

The font was the same as it was for the adults (Courier New), but the font size was 36, instead of 14. If the participant indicated that he understood, and wanted to try the practice items, he then moved on to that phase of the test.

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[55] Two laptop computers were used for the Spanish-dominant bilingual children. One was a Toshiba Satellite A45-S121 and the other a Gateway 400SD4. Both were running DMDX on Windows XP. The input device for both was a *Saitek P880 Pad USB* game controller.

As in the adult experiments, the practice items were very similar to the items in the main task, except as noted above, and in two other ways. One difference was that the test administrator was in control of when the items appeared. That is, the items did not appear automatically after the previous item was responded to. Rather, the test giver decided when it was appropriate to move on to the next item, and did so with a press of the mouse button. Normally, this was directly after the previous item, but sometimes delays were necessary if there were disruptions in the environment (e.g., other children entering the library, interruptions on the school intercom), at which point the test giver took notes on the item the participant was responding to at the time of the disruption. This rarely happened. Another difference was that there was no feedback to the participant. It was thought that negative feedback (either explicitly, or implicitly through a lack of positive feedback) would make the participant feel more anxious. It was clear during the experiment that the participants were aware of which items they got right and wrong.

If the participant completed more than half of the practice items correctly, then he moved on to the main experiment, if he wanted. In fact, all the participants completed the practice items with more than 50% accuracy, and all but one (as noted above) were willing to move on to the main task.

The main task proceeded in the same way as it did for the adults, except for font size, and the facts that the test giver both controlled when items would be presented and paused the experiment between letter blocks. As noted above for the practice items, the test giver controlled when trials would be presented during the experiment in order to maintain some control over disruptions and remedy any off-task behavior on the part of the participant. The test giver paused the task between letter blocks to check that the participant was still willing to continue the experiment, to inform him that the search letter was about to change, and to let him know that he should adjust for that.

At the end of the experiment, the test giver told the participant that the computer was measuring how fast he responded to the words. It was explained to him, as best as possible, what milliseconds and error rates were, and how he had performed. This was always communicated in a positive way (e.g., "¡Lo hiciste muy bien!" [You did really well!]). The test giver then told the participant that the test givers would explain the purpose, design, and results of the experiment at a later date in a group setting. We did this within a few weeks of starting the experiments with this participant group (see the paragraph below). Finally, the test giver thanked the participant for his cooperation and let him know that we would see him soon in the group setting.

The participants were compensated in two different ways. All the students at those grade levels, including our participants, were compensated through relevant, educational materials. Within a few days of finishing testing, the participants were also given an elaborate debriefing ceremony with food and individual participation certificates. These forms of compensation were affordable and feasible in Argentina. The total amount came to US$10 per participant, the same amount of compensation given to participants in the US.

6.1.3 Predictions

The predictions for this group are similar to those for the Spanish-dominant developing-bilingual adults in Chapter 5 (p. 176). But in contrast to the bilingual adults, the bilingual children were still developing literacy skills in their L1. This makes predictions for the group a little less certain. The isolated double-vowel (IDV) facilitation seen in experiments 1 and 3B, might simply be the result of many years of experience reading the Spanish alphabet. It is not clear that these children have had enough experience to start showing the effect.

Regardless, with increased exposure to English orthography, the Spanish-dominant bilinguals should eventually begin to exhibit reading behavior similar to that of the monolingual English adults. They should start showing equal congruency effects between single- and double-vowels in either YES responses, or NO responses, or both.

6.1.4 Results

The same rejection, cutoff, and trimming procedures as in experiment 1 (p. 101) were applied to the data in this experiment. Participants with error rates above 20% were not included in the analyses. As noted above, there were two such participants. All reaction times below 200 ms or above 1,000 ms were deleted for each participant. The children in this study had reaction times short enough on average to apply the same cutoff procedure as for the adults. For each participant, reaction times were also trimmed to ± 2SD from that participant's mean.

6.1.4.1 Low-proficiency group

The resulting mean reaction times for the low-proficiency group can be seen in Figure 17. Mean errors, reaction times, facilitation, and benefit can be seen in Table 26.

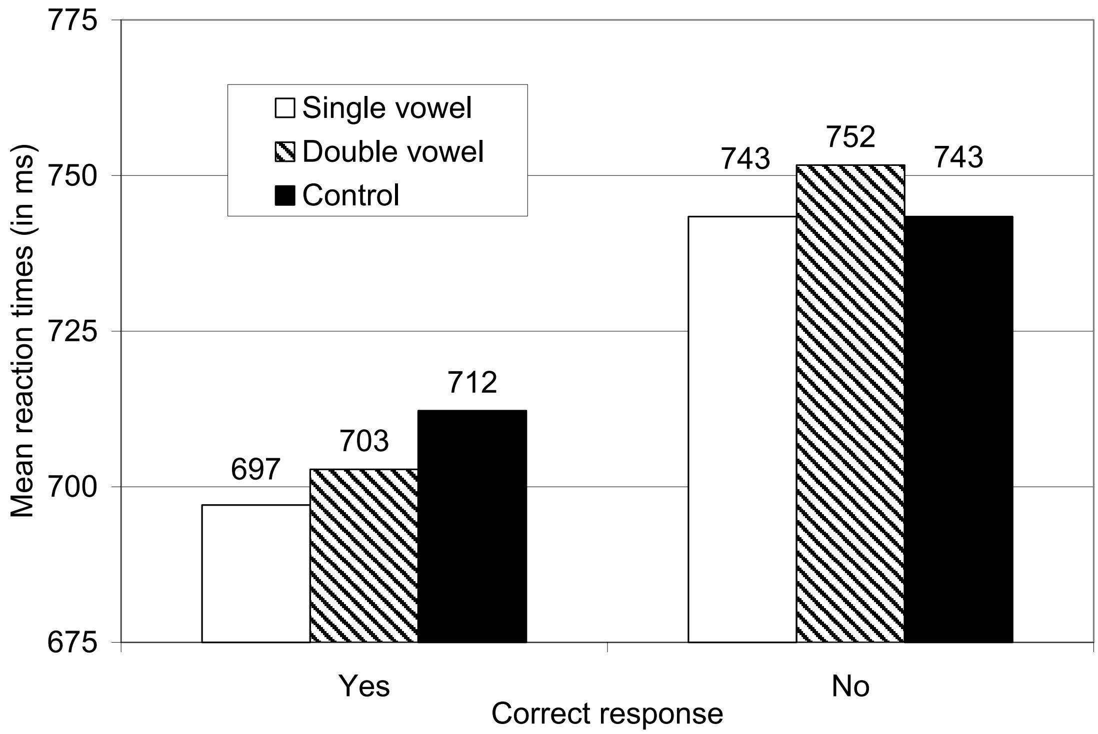

FIGURE 17. Mean reaction times (in ms) for Spanish-dominant bilingual children with low proficiency in English (N=27) on age-appropriate English materials.

In the analysis of reaction times, a 2x3 factorial ANOVA (Response x Prime Type) showed a main effect for response. This was significant in both the analyses by participant and by item, $F_1(1,24) = 23.90$, $p < .0001$, $F_2(1,30) = 21.95$, $p < .0001$. There were no other main effects or interactions. In the analysis of error rates, there were no significant main effects or interactions.

TABLE 26. Mean Error Rates, Reaction Times (RT), Facilitation, and Benefit for Spanish-dominant Bilingual Children with Low Proficiency in English (N=27) on Age-Appropriate English Materials as a Function of Response and Prime Type.

	Dependent measures					
Response and vowel prime type	Error rate (%)		RT (ms)		Facilitation (ms)	Benefit (ms)
YES						
Single *U→judge→LUNCH*	4.9	(6.2)	697	(103)	15	6
Double *U→build→LUNCH*	4.6	(6.3)	703	(107)	9	
Control *U→fight→LUNCH*	7.1	(10.0)	712	(101)		
NO						
Single *U→judge→BENCH*	5.0	(8.8)	743	(79)	0	-9
Double *U→build→BENCH*	5.3	(9.9)	752	(103)	-9	
Control *U→fight→BENCH*	6.5	(8.3)	743	(99)		

Note. Facilitation = [Control]-[Single] and [Control]-[Double]. Benefit = [Double]-[Single]. SD in parentheses.

The only conclusion that can be draw from the statistical analysis is that the low-proficiency group responded faster to YES responses than to NO responses.

6.1.4.2 High-proficiency group

The mean reaction times for the high-proficiency group can be seen in Figure 18. Mean errors, reaction times, facilitation, and benefit can be seen in Table 27.

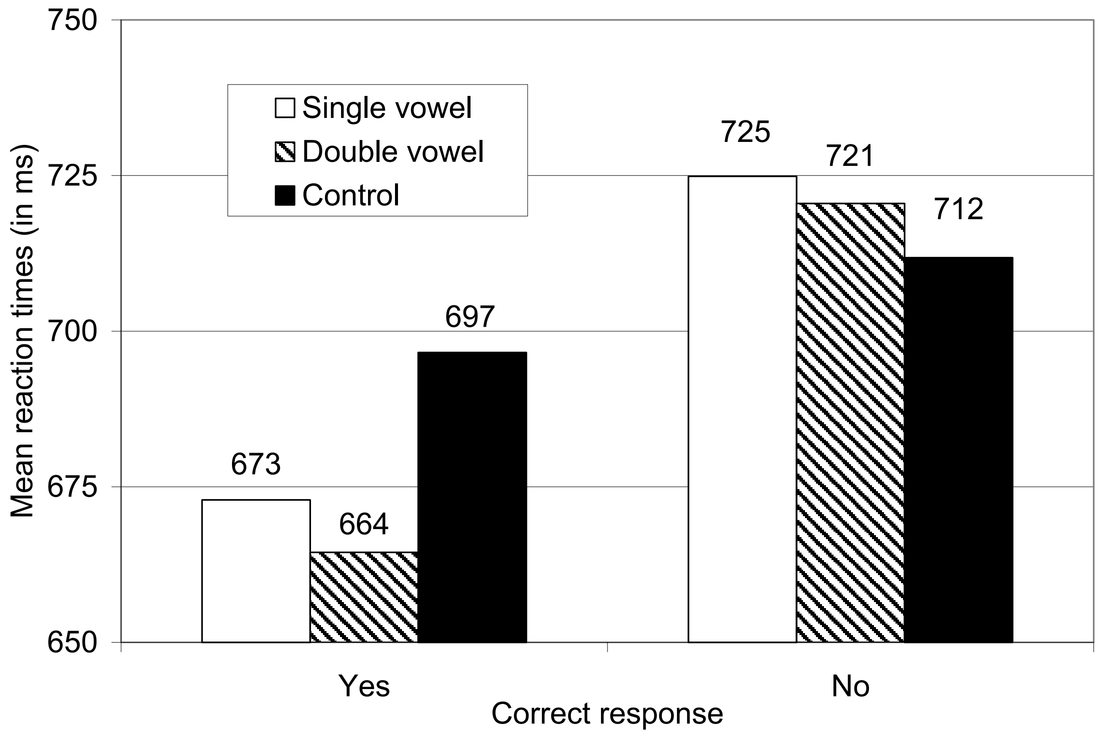

FIGURE 18. Mean reaction times (in ms) for Spanish-dominant bilingual children with high proficiency in English (N=36) on age-appropriate English materials.

In the analysis of reaction times, a 2x3 factorial ANOVA (Response x Prime Type) showed a main effect for response. This was significant in both the analyses by participant and by item, $F_1(1,33) = 34.42$, $p < .0001$, $F_2(1,30) = 34.41$, $p < .0001$. There was no main effect for response, but the interaction between response and prime type was significant by participant and item, $F_1(1,33) = 34.42$, $p < .0001$, $F_2(1,30) = 34.41$, $p < .0001$.

Planned comparisons showed significant differences in the YES responses. Both the 24-ms and 33-ms response congruencies for the single- and double-vowel primes, respectively, were significant by both participant and item. The 9-ms single-vowel detriment was not significant in either analysis. Only one comparison in the no responses was significant. This was the 13-ms inhibition for the single-vowel prime, but it was only significant by participant.

A 2x3 factorial ANOVA (Response x Prime Type) for error rates showed one main effect, response. This was significant by participant and item, $F_1(1,33) = 4.45$, $p < .045$, $F_2(1,30) = 7.63$, $p < .01$. No other main effects or interactions were significant. In general, participants made significantly fewer errors on NO responses than on YES responses.

TABLE 27. Mean Error Rates, Reaction Times (RT), Facilitation, and Benefit for Spanish-dominant Bilingual Children with High Proficiency in English (N=36) on Age-Appropriate English Materials as a Function of Response and Prime Type.

Response and vowel prime type	Dependent measures: Error rate (%)		Dependent measures: RT (ms)		Facilitation (ms)	Benefit (ms)
YES						
Single *U→judge→LUNCH*	5.8	(9.1)	673	(109)	24*	-9
Double *U→build→LUNCH*	4.4	(5.5)	664	(104)	33*	
Control *U→fight→LUNCH*	5.3	(6.7)	697	(106)		
NO						
Single *U→judge→BENCH*	3.3	(6.7)	725	(114)	-13[P]	-4
Double *U→build→BENCH*	2.4	(3.9)	721	(112)	-9	
Control *U→fight→BENCH*	3.1	(5.8)	712	(111)		

Note. Facilitation = [Control]-[Single] and [Control]-[Double]. Benefit = [Double]-[Single]. SD in parentheses.
* Significant by participant and by item
[P] Significant by participant

6.1.5 Discussion

It appears that the group of bilingual children with higher proficiency in English showed congruency effects more strongly than the lower proficiency group. This could be attributed to higher statistical power, reflected in the different numbers of participants in each analysis, but the magnitude of the differences in the older group is larger, suggesting that power is not the only factor here.

At the same time, it does not appear that the children are showing an IDV facilitation effect in English. The children did not seem to show transfer of alphabetic processing knowledge from their L1 to their L2, at least not in the way that their adult counterparts seemed to. It is possible that they were young enough to quickly develop English-like alphabetic processing knowledge before they had developed Spanish-like alphabetic processing knowledge. If this was the case, there would have been no distinct L1 processing knowledge to be transferred in the first place.

But another explanation is probably more likely. It is possible that in order for the IDV facilitation effect to appear even in Spanish, Spanish readers would have to have had a great deal more experience in reading than the experience held by students in grades 5-8. These children may have shown an effect much like the adult English monolinguals (but in YES responses) because they were not at the stage yet where they could automatically activate syllables and/or abstract syllable structure for rapid word recognition. This skill may only emerge as they approach adulthood. In this is the case, the only information available to such relatively inexperienced readers would be letter information. This is simply a logical possibility; it needs further testing. The trend seen in the 9-ms single-vowel detriment may suggest that some of these children are on the verge of developing the processing knowledge that the adult monolingual Spanish readers appear to have.

6.2 Experiment 4B: English monolingual children

The next experiment also relates to the relationship between literacy development and response congruency in the masked-priming paradigm. In it, I try to find out how early congruency effects emerge, not in bilingual, but in monolingual English children in grades 3 to 5. This may provide some insight into the mystery just described with the Spanish-dominant bilingual children.

The main question addressed in this chapter is the age at which congruency effects emerge. On the whole, it is difficult to demonstrate congruency effects in masked-priming experiments at very short prime durations. In fact, it is not clear that it has been done with 33-ms primes before (K. I. Forster, personal communication, April 26, 2005). The congruency effects in the studies above show that normal adult English readers can clearly glean sufficient information from primes at very short prime durations to make subconscious decisions on them. But it is worth asking how early in reading development this ability begins to emerge.

This issue bears on automaticity in reading. It is generally accepted that, except for knowledge of sight vocabulary, most children read very much like adults by the fifth grade in terms of explicit GPC knowledge (Jackson & Coltheart, 2001). But automaticity of word recognition is another issue. Several researchers have begun looking at automaticity of word recognition with masked priming (Castles, Davis, & Forster, 2003;

Castles, Davis, & Letcher, 1999; Pratarelli, Perry, & Galloway, 1994). Without going into the theoretical ideas in each paper, the results of these studies indicate that children as young as 7 or 8 can process orthographic information automatically even if they are not aware of it. But these effects were priming effects in the strict sense (e.g., identity priming, form priming, phonological priming), not congruency effects like one might measure, for instance, in a semantic-categorization task. The last experiment in this dissertation probes whether congruency effects appear at short prime durations among young, monolingual readers of English in the third to fifth grades.

Letter detection is an ideal candidate for such a probe since it is relatively simple, whereas semantic categorization would seem to rely on more sophisticated mental operations.

The results of this experiment may provide some insight into the results with the Spanish-dominant developing-bilingual children. If so, this will be addressed at the end of the chapter in the summary. It may also have some broader educational implications. If so, these will also be discussed in the summary.

6.2.1 Participants

The 54 participants in this study were young, monolingual readers of English. They were 3rd to 5th graders from a public elementary school in the Tucson Unified School District in Arizona. They were not taking any foreign languages, so there is little reason to describe their curriculum in much detail. There were 31 girls and 23 boys.

There were 19 in the 3rd grade, 20 in the 4th grade, and 15 in the 5th grade. The mean age was 7;5 years old.

Of the 54 participants in this study, two had background characteristics that merited removing their data from the analysis. Another participant's data were randomly deleted to keep the number of experimental files balanced. All the rest had normal or corrected vision, and nothing unusual about either their language or learning backgrounds. And none of them had error rates over 20%. Overall, this means that 51 participants' data were included for analysis. There were 30 girls and 21 boys in this final analysis group. There were 18 in the 3rd grade, 19 in the 4th grade, and 14 in the 5th grade. The mean age of these 51 children was 7;6 years old.

There were not enough participants to divide into high- and low- proficiency groups. Instead, I will analyze this entire group's reaction times as a whole to see if there are congruency effects.

6.2.2 Procedures

The materials and procedures for this group were identical to those with the Spanish-dominant bilingual children with just a few minor exceptions.[56] The materials differed only in the language in which they were presented. As was the case for all the

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[56] One laptop computer was used for the monolingual English children. This was a Toshiba Satellite A45-S121, running DMDX on Windows XP. The input device was a *Microsoft SideWinder Game Pad USB* game controller.

experiments presented thus far, directions were given in the participants' dominant or native language, English (see Appendix I).

I tested each of the children, one by one, according to a schedule set up between the student's teacher and me. On taking a participant out of class to test, I began a short conversation intended to make sure he remembered who I was, why I was taking him out of class, and verify that he was comfortable with me. During this conversation, I also reviewed the two tasks. At the end of the conversation, I also asked once again for his assent. All the students in this group were willing to participate.

The experiment was carried out in a quiet corner in the school library, off limits to other students. The participant faced a corner where he could not see any activity in the rest of the library. And there was one test giver, not two.

Participants were compensated US$10 each in the form of materials purchased for the school (e.g., books, games). These materials were chosen by the participants' teachers, and related directly to the further education of the students in that grade level. I also came back later at a pre-arranged time and gave the children and teachers a presentation of what the experiment was about.

Otherwise, all materials and procedures were identical to those described in Section 6.1.2 with the Spanish-dominant bilingual children.

6.2.3 Predictions

These participants were young. It is possible that they would not have had sufficient experience with or mastery of the orthography to have acquired enough automatic word-recognition ability to exhibit any congruency effects. This is particularly true of ones less proficient in reading English.

To see if they exhibited congruency effects, I submitted the data to an omnibus test to probe for congruency effects in the larger group. If children in grades 3-5 generally have the ability to extract information from briefly presented masked primes to make decisions, then there should be significant congruency effects overall.

6.2.4 Results

The same rejection, cutoff, and trimming procedures as in experiment 1 (p. 101) were applied to the data in this experiment, except that all means above 1,500 ms were deleted instead of 1,000 ms. The reasoning for this is that these participants were much younger and took substantially longer to respond on average, with many reaction times above 1,000 ms. No participant in this group had error rates higher than 20%, so no data were removed for this reason. All reaction times below 200 ms were deleted. And for each participant, reaction times were trimmed to ± 2SD from that participant's mean. The resulting mean reaction times can be seen in Figure 20. Mean errors, reaction times, facilitation, and benefit can be seen in Table 28.

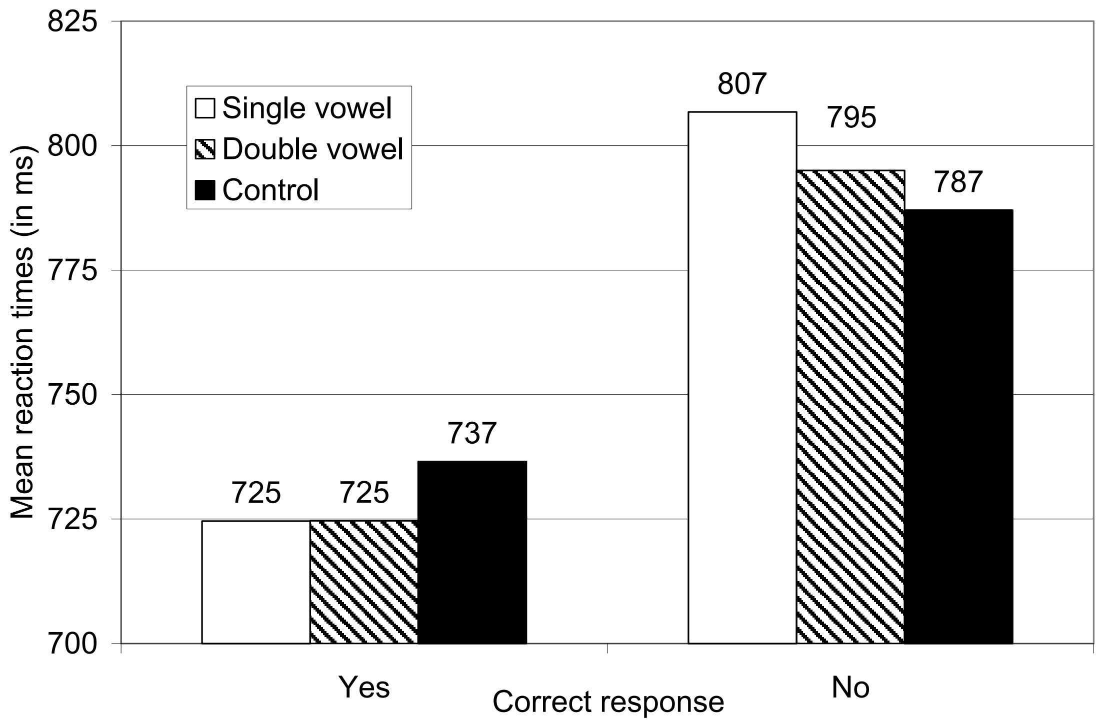

FIGURE 19. Mean reaction times (in ms) for English monolingual children (N=51) on age-appropriate English materials.

In the analysis of reaction times, a 2x3 factorial ANOVA (Response x Prime Type) showed a main effect for response. This was significant in both the analyses by participant and by item, $F_1(1,48) = 91.78$, $p < .0001$, $F_2(1,33) = 112.20$, $p < .0001$. There was no main effect for prime type, $F_1 < 1$, $F_2 < 1$. The interaction between response and prime type was significant in both analyses, $F_1(2,96) = 3.65$, $p < .03$, $F_2(2,60) = 3.58$, $p < .04$.

Planned comparisons showed no significant differences in the YES responses. The closest was a marginal effect in the analysis by item for the 12-ms facilitation for the single-vowel primes. There was one significant difference in the NO responses. The 20-ms inhibition for the single-vowel primes was significant by participant and item.

In the analysis of error rates, a 2x3 factorial ANOVA (Response x Prime Type) showed a main effect for response, which was significant by both participant and item, $F_1(1,48) = 7.33$, $p < .01$, $F_2(1,30) = 5.54$, $p < .03$. There was no main effect for prime type. There was a significant interaction between response and prime type in the analysis by participant only, $F_1(1,96) = 3.61$, $p < .04$. The interaction was marginal in the analysis by item, $F_2(1,60) = 2.96$, $p < .06$.

TABLE 28. Mean Error Rates, Reaction Times (RT), Facilitation, and Benefit for Monolingual English Children (N=51) on Age-Appropriate English Materials as a Function of Response and Prime Type.

Response and vowel prime type	Dependent measures: Error rate (%)		Dependent measures: RT (ms)		Facilitation (ms)	Benefit (ms)
YES						
Single *U→ju̲dge→LU̲NCH*	6.2	(7.4)	725	(181)	12	0
Double *U→bu̲i̲ld→LU̲NCH*	6.4	(7.9)	725	(178)	12	
Control *U→fi̲ght→LU̲NCH*	8.8	(8.2)	737	(165)		
NO						
Single *U→ju̲dge→BE̲NCH*	5.7	(7.7)	807	(191)	-20*	-12
Double *U→bu̲i̲ld→BE̲NCH*	5.9	(6.3)	795	(184)	-8	
Control *U→fi̲ght→BE̲NCH*	3.9	(6.6)	787	(183)		

Note. Facilitation = [Control]-[Single] and [Control]-[Double]. Benefit = [Double]-[Single]. SD in parentheses.
* Significant by participant and by item

6.2.5 Discussion

The results of this experiment suggest that congruency effects are at least beginning to emerge among 3rd to 5th graders. A significant, single-vowel inhibition effect appeared in the NO responses. Interestingly, however, it did not occur anywhere else.

One possible explanation is that graphemes are the basic unit of visual word recognition, and the vowel digraphs interfered with letter processing, at least in the NO responses. But the other experiments in this dissertation thus far suggest that letters are the basic perceptual reading unit. It may be possible to account for the single-vowel inhibition in the NO responses by, again, appealing to graphemic processes along the nonlexical route.

It is possible that double-vowel inhibition failed to appear in the NO responses because the double-letter primes activated multi-letter graphemes that interfered with the identification of the individual letters. This prevented the participants from making strong subconscious decisions on the primes, leading to less inhibition when responding to targets. In contrast, the single-vowel primes, by activating just one grapheme, allowed the participants to make clearer subconscious decisions. This clarity led, in turn, to more inhibition in the NO responses. On the surface, this explanation seems to conflict strongly with the interpretation of experiment 2A, where equal inhibitory effects were evident between single- and double-vowel primes. Instead, it seems more in line with experiment 2B with 48-ms masked primes, where I argued that there was enough time for double-vowel primes to activate multiple graphemes.

In order to resolve this conflict, I need to stipulate that under certain circumstances, it is possible for participants to activate multiple graphemes with primes of only 33 ms. This special circumstance would be found in participants who respond slowly to the experiment. Recall that overall mean reaction times in experiment 2A were fairly short. The mean reaction time was 499 ms (*SD* = 81) in the YES responses, and 539 ms (*SD* = 80) in the NO responses. In contrast, the children in this last experiment had much slower overall reaction times. These were 729 ms (SD = 174) in the YES responses, and 796 (SD = 185) in the NO responses. The differences are 230 ms in the YES responses, and 257 ms in the NO responses, and the standard deviation for the younger group is more than double what it was for the adults. Undoubtedly, much of wide variance reflects developmental differences among early readers. Regardless, it might be the case that the extra time taken by the younger participants to respond allowed more graphemic activation to build up and interfere with the identification of the letter in the target. That is, graphemes were not active in the case of the adults by the time they responded to targets, but were active in the case of the children.

This explanation has precedent in an analogous experiment with children. Davis, Castles, and Iakovidis (1998) found that, in a go/no-go lexical-decision task, neither homophonic primes (e.g., witch → WHICH) nor pseudohomophonic primes (e.g., rait → RATE) facilitated reaction times to targets better than nonhomophonic controls (e.g., dent → WORK, tenk → TALK).[57] But noting the wide variability in reaction times, the

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[57] A go/no-go lexical-decision task involves deciding whether letter strings are words. If the participant thinks the string is a word, then he presses a button as quickly as he can. If he thinks it is not, he does nothing. This task is often used with young participants since the task demands are lower than forced-choice experiments.

researchers suspected that phonological processes might indeed have exerted a late influence (as in the dual-route cascaded model). If so, only children with relatively longer reaction times would have shown the expected homophonic and priming effects. They split the children's data into two groups, one with faster mean reaction times and one with slower mean reaction times. The homophonic facilitation of the slower group was 15 ms, while the faster group was 4 ms. The slower group showed "tentative" evidence of late phonological influence in word recognition (Davis, Castles, & Iakovidis, 1998, p. 642).

The variation in this experiment was also high, so I made two groups based on the relative speed of overall mean reaction times (across all items), and then re-examined the data for differences between the groups. The two groups were classified into those whose mean reaction time was above 700 ms, and those whose mean reaction time was slower. There were 25 participants in the faster group, and 26 in the slower group.

The trends were revealing, though they should be interpreted with caution since counterbalancing was not possible, and no statistical analyses were performed. Both groups were faster in the YES responses than in NO responses. In the YES responses, the faster responders showed equivalent congruency with single- and double vowel primes (18 and 19 ms, respectively). But in the NO responses, single-vowel primes seemed to inhibit responses more than double-vowel primes (by 19 and 5 ms, respectively). In contrast, the slower responders showed very little facilitation after either single- or double-vowel primes in the YES responses (6 and 5 ms, respectively). But in the NO responses, they showed more inhibition after single-vowel primes than after double-vowel primes (by 20 and 10 ms, respectively).

Faster participants showed effects that fit a model in which letter influence precedes grapheme influence, as on the nonlexical route in the DRC. Letters affected reaction times in the faster, YES responses, whereas graphemes started affecting reaction times in the slower, NO responses. In the slower group, however, letters did not seem to have much of an effect on reaction times in the faster, YES responses, whereas graphemes did seem to affect reaction times in the slower, NO responses.

A tentative explanation for these differences is that the faster group reacted fast enough to show evidence of the letter-as-percept view. That is, for this group, double-vowel primes in the YES responses (which were faster overall than NO responses) did not have time to activate inhibitory graphemes. But in the NO responses (which were slower overall than the YES responses), double-vowel primes did have enough time to activate inhibitory graphemes.

Unlike the post-hoc analysis of Davis, Castles, and Iakovidis (1998), the results of the slower group in my experiment are more difficult to interpret. Perhaps the slower group reacted so slowly that double-vowel primes had enough time in the YES responses to activate graphemes. But this still should have resulted in more facilitation from single-vowel primes than from double-vowel rimes in YES responses. Both prime types were quite weak in terms of facilitation. It is possible that the slower group's data should be ignored. The average distance from the overall mean for this group was high (*SD* = 140 ms). In contrast, the average distance for the faster group was almost one third of that (*SD* = 53 ms).

Perhaps a better way to probe letter-grapheme sequence effects would be by keeping the prime duration at 30 or 33ms, but inserting a backward pattern mask for various durations before the target appears. This technique is fraught with its own problems, like increased visibility of the prime (Forster, Mohan, & Hector, 2003). But if awareness of the prime can be controlled for, and it is possible for graphemic information to build up after a 33-ms prime, then grapheme effects should become stronger as the duration of the backward pattern mask is extended, at least to some degree.

6.3 Summary

The two experiments in this chapter depended on the same English materials and experiment, but probed two different questions. The experiment with the Spanish-dominant bilingual children was a continuation of the previous chapter that attempted to see how L1 alphabetic processing knowledge in Spanish might transfer to English. These children were in grades 5 to 8, so it was assumed that they would have had enough reading background in their L1 to transfer to their L2.

In the first analysis, it appeared that they were not transferring alphabetic processing knowledge from their L1. There were no significant effects in the group with lower proficiency in English. This is where one would have expected the strongest IDV facilitation effects unless they were too young to have developed them in Spanish. This may have been the case.

In the group with higher proficiency in English, it looked as if there might be a trend for IDV facilitation in the YES responses, but it was not significant. However, there were significant single- and double-vowel facilitation effects in the YES responses for this group. This is not what would have been expected if either temporary or persistent alphabetic processing transfer were the cause. If that had been the case, then, again, the effect should at least have occurred with the lower English-proficiency group. It might be possible however, that the IDV effect would only emerge among highly advanced readers of Spanish. The children of this study may not have been that advanced, though there is a small trend towards IDV facilitation.

The second experiment in this chapter addressed the age at which language-specific alphabetic processing knowledge emerges. The experiment with younger English monolinguals in grades 3-5 (which was identical to the one given to the Spanish bilingual children) showed emerging congruency effects. But the nature of the effects was a little different than expected.

Recall that in experiment 2A with 33-ms primes, monolingual English adults showed equivalent single- and double-vowel inhibitory effects in the NO responses (nothing significant in the YES responses). In contrast, though the young children also showed inhibitory trends in the NO responses, only the single-vowel primes were significantly inhibitory. This might support a grapheme-as-percept view. But since it was unreasonable to disregard the evidence so far in this dissertation indicating that the congruency effects were caused by letters activating phono-graphemic units along some sort of nonlexical route (as in the dual-route cascaded model), I sought an explanation more consistent with the letter-as-percept view.

One alternative explanation relies on a widely-accepted assumption among dual-route theorists: namely, that letter-to-grapheme processes along the nonlexical route are generally slow in comparison to processes along the lexical route. If this is so, then it is possible that the generally slower reaction times among the children in this experiment (compared with the relatively faster reaction times among the adults in experiment 2A) allowed enough time for grapheme activation to interfere with letter detection in the primes. This would have resulted in weaker subconscious decisions after double-vowel primes, which in turn, would help the participants in the NO responses, since they would not have to contend with a solidly incongruent decision on the target.

To investigate this possibility, I split the participants into slow and fast responders following Davis et al. (1998) to see if late responders showed this type of response pattern. The trends in this informal analysis were different than expected, but they provided weak confirmation that letters are activated early and graphemes later. The faster responders showed equivalent congruency trends for single- and double-vowel primes in the YES responses, but non-equivalent congruency trends in the NO responses, where single-vowel primes looked to be more inhibitory than double-vowel primes. Since the NO responses were on average much longer than YES responses, it is possible that only letter-based information could be derived from the primes when the answer was YES, whereas grapheme-based information could be derived when the answer was NO since there was more time for activation to occur.

Unfortunately, the data from the slower responders was less clear. The congruency trend in their NO responses was similar to that of the faster responders. But the slower responders should also have shown a stronger congruency trend in the YES responses after single-vowel primes. Instead, both congruency trends were weak and roughly the same. Their data may not be reliable however, since the variance in that group was so high relative to the faster group.

If it is true that reading proficiency was related in some way to performance on the experiment for children of both language backgrounds, then there is a small discrepancy between the results of the two groups that is worth noting, and perhaps investigating in further research. Recall that IDV facilitation trend for the Spanish-dominant bilingual children was not significant. It may only appear among readers more advanced than those in grades 5-8. In contrast, grapheme-activation effects seemed to appear fairly early among the native English children. Assuming both are effects that take place along the nonlexical route, then it appears that native English children develop graphemic representations earlier than native Spanish children develop (presumed) syllabic representations. This makes a certain amount of sense since there will always be more syllables than graphemes in a language. The late development of syllabic representations among native Spanish children would be predicted by the sheer number of such representations that need to be made. In fact, Ehri (1999) incorporates this type of learning into the last phase of her phase model to account for sensitivity to orthographic rimes among highly proficient readers of English (see Section 2.3.2 for my review of this aspect of her model). But for now, this potential difference between the two language groups serves as little more than speculation for future exploration.

CHAPTER 7 GENERAL DISCUSSION

In this chapter, I will return to the four issues enumerated in Section 1.1 (p. 17): (a) What is the basic unit of visual word recognition in alphabetic orthographies? (b) Do readers of different alphabets process the same letter groups similarly or differently across languages? (c) If so, does this knowledge transfer across languages? And (d) When does this automatic alphabetic processing knowledge begin to emerge?

7.1 The basic unit of visual word recognition and cross-linguistic alphabetic processing

The first two questions were addressed in Chapter 4, in experiments 1 with Spanish monolinguals (Section 4.1), and in experiments 2A through 2D with English monolinguals (Sections 4.2-4.4). Both the letter- and grapheme-as-percept views reviewed in Chapter 2 predicted that although the Spanish monolingual adults would show congruency effects, they would show no single-vowel benefit (in the YES responses) or detriment (in the NO responses). In English, the grapheme-as-percept view predicted single-vowel benefit, whereas the letter-as-percept view did not.

The results of the experiment with Spanish monolinguals were unexpected. It turned out that the Spanish monolingual adults exhibited an isolated double-vowel (IDV) facilitation effect in the YES responses. That is, reactions times after double-vowel primes in the YES responses were fastest overall. Neither view predicted this.

I devised an explanation that drew from recent findings regarding the strong role that both syllables and abstract syllable structure seem to play in Spanish visual word recognition, and the logic of having syllables, not graphemes, represented on the nonlexical route. Combined, these facts and observations suggest that the abstract syllable structure of the single-vowel primes (CVC) was congruent with that of the targets (CVC), which led to persistence or reinforcement of syllable candidates activated by the prime and target. In contrast, the abstract syllable structure of the double vowel primes (CVV or VCC) was incongruent with that of the targets (CVC), leading to lack of persistence or reinforcement of syllable candidates, less competition, and faster reaction times.

Again, some might find it difficult to fathom that Spanish readers might derive letter information from syllables. But this is no stranger than Rey et al's (2000) claim that native English readers make letter decisions from graphemes since there are so few multi-letter graphemes in Spanish, and representing them on the nonlexical route would net little information.

The experiments with the English monolingual adults were also revealing. In experiment 2A with 33-ms primes, there was no effect in the YES responses, but equivalent congruency (inhibitory) effects in the NO responses (Section 4.2.4). In experiment 2B with 48-ms primes, a single-vowel benefit started to emerge in the YES responses, along with a single-vowel detriment in the NO responses (Section 4.3.3). But in the experiment with 67-ms primes, the single-vowel benefit and detriment disappeared again, leaving equivalent response-congruency effects in both the YES and NO responses

(Section 4.3.3). Finally, I replicated the findings of Rey et al.'s (2000) experiment 1A, with a modification of their materials.

All these experiments lead to the conclusion that graphemes do play a role in letter detection, but not at the perceptual level. Rather, letter detection takes place along the nonlexical route, and graphemic effects emerge depending on the time available to make decisions. When primes are short in duration as in the case of 33-ms primes, only letter-based information can be extracted from the primes. This explains the equivalent response-congruency effect in the NO responses (see Table 14). At 48 ms, however, participants begin to experience the effects of grapheme activation along the nonlexical route. The double-vowel primes begin to activate vowel digraphs, which just add to the pool of grapheme candidates already activated by the individual vowel letters. This slows reaction times after double-vowel primes (see Table 15). At 67 ms, awareness of the primes allows the participant to disregard the graphemes activated by the primes altogether, and simply concentrate on the targets, which are graphemically equivalent in form. She is left only with the subconscious decision she made on the primes, thereby accounting for the lingering congruency effects, equivalent again between single- and double-vowel primes (see Table 16). Finally, the single-vowel benefit (Rey et al's (2000) digraph effect) reappears when the participants have to make decisions on targets that have double vowels (See Table 18). These effects are still graphemic in nature. The reason the single-vowel benefit failed to appear with the 67-ms primes was that the participant was able to concentrate her attention fully on the targets, which did not differ in any way.

There was one apparent conflict in my different explanations for the results with the Spanish and English monolingual adults. With the Spanish monolingual adults, I argued that syllabic representations were activated on the nonlexical route after only a 33-ms prime. But with the English monolingual adults, I argued that it took longer than 33 ms to activate graphemic representations along the nonlexical route. This contradiction might be reconciled by appealing to the weak version of the orthographic depth hypothesis (Katz & Frost, 1992) or the universal phonological principle (Perfetti, 2003; Perfetti, Zhang, & Berent, 1992). These hypotheses suggest that phonological activation should be relatively rapid in shallow orthographies like Spanish, and relatively slow in deep orthographies like English. This would account for the relatively rapid syllabic activation in the case of the Spanish experiment.

Overall, it appears that the grapheme-as-percept view is incorrect. Graphemes do have a role to play in letter detection, but only through late activation along the nonlexical route, not through perception at the abstract-unit stage. Furthermore, it seems there are cross-linguistic differences in how this plays out. In Spanish, decisions about letters can be made from abstract letter units (early) or syllabic units (late). But syllable activation is so fast in Spanish that it is hard to measure the role of abstract letters. In fact, I can only assume that they must play a role. It may be that syllabic graphemes are activated at the perceptual level in Spanish, but not in English. This would be difficult to believe, but it is possible. In English, the interpretation is clearer. Letters are detected via abstract letters or graphemes, depending on the prime duration. Letter effects can be seen at 33 ms, whereas grapheme effects appear after that. The activation process is relatively slow compared to Spanish.

7.2 Transfer of alphabetic processing knowledge

The issue of transfer was addressed in Chapter 5 with bilingual adults, and in Chapter 6 with Spanish-dominant bilingual children. In the adult data, the bilinguals with relatively low proficiency in their L2 showed effects in their L2 consistent with their monolingual counterparts in the L1. That is, English-dominant bilinguals with low proficiency in Spanish tended to show equal single- and double-vowel facilitation effects in Spanish (see Table 19), whereas Spanish-dominant bilinguals with low proficiency in English showed an IDV facilitation effect in English (see Table 21). These results were not surprising since low-proficiency L2 learners have little more to operate on than the alphabetic processing knowledge of their L1.

The results of the high-proficiency bilinguals were not so clear. The English-dominant bilinguals with high proficiency in Spanish seemed to have relied on English-like alphabetic processing knowledge when performing the experiment in Spanish (see Table 20). But these bilinguals were drawn from a population of undergraduate students who were either studying Spanish, or who had done so recently. None of them were immersed in Spanish at the time. It is possible that the relatively arbitrary division into high- and low-proficiency groups via the Letter-Word Identification subtest of the

WMLS-Spanish was insufficient to distinguish qualitatively different proficiency levels in the language.

In contrast, the Spanish-dominant bilinguals with high proficiency in English were definitely highly proficient in English. Most were native Spanish-speaking graduate students studying in an English-based curriculum at the University of Arizona. Unfortunately, there were too few of these participants to generate enough statistical power to see significant results (see Table 22). Furthermore, participants in one of the counterbalanced files performed differently from participants in the other two files, possibly leading to the nullification of effects that otherwise might have emerged. In any case, the trend in their data suggests that they have begun to acquire English-like alphabetic processing knowledge.

The results of the Spanish-dominant bilingual children doing the experiment in English were more mysterious. This group was also divided into high- and low-proficiency groups using the Letter-Word Identification subtest of the WMLS-English. The low-proficiency group did not show any effects at all (see Table 26). But the high proficiency group showed what appears to be equivalent congruency effects for single- and double-vowel primes in the YES responses (see Table 27). This is not what would be predicted if they were transferring alphabetic processing knowledge from their L1. They may have been young enough to have quickly developed English-like alphabetic processing knowledge before Spanish-like processing knowledge could transfer, but this seems unlikely.

Instead, it seems more likely that the IDV facilitation effect would emerge relatively late, among much more advanced readers of Spanish than those in grades 5-8. However, it looks like at least some of them may already be developing such alphabetic processing skills.

In sum, native Spanish- and native English-reading adults both seem to transfer alphabetic processing knowledge from their L1 to their L2, at least at first. Whether they eventually acquire L2-like processing knowledge was not resolved in this study. One might speculate that there is a better chance that they do than that they do not. But for now, the data are inconclusive. Native Spanish-reading children, on the other hand, may only begin showing IDV facilitation relatively late, after some developmental point in L1 reading has been reached (e.g., the ability to read at a certain speed). For this reason, they did not show transfer effects in English because they had no such alphabetic processing knowledge to transfer.

7.3 Age at which congruency effects emerge

The last issue mentioned at the beginning of this dissertation was the age at which congruency effects emerge. Previous studies have already shown that children start showing priming effects under masked priming within just a few years of learning to read (Castles, Davis, & Forster, 2003). But these were priming effects, per se, which tell us little about decision congruency. My last experiment was an attempt to see how reading proficiency was related to response-congruency effects, and whether children who are still learning to read can subconsciously extract orthographic information for their decisions.

The experiment showed that children in grades 3-5 do show congruency effects overall (see Table 28). Furthermore, when only the faster participants' data are analyzed, the effects tend to support the letter-as-percept view with a late grapheme-to-phoneme effect. The slower participants' data were more ambiguous.

7.4 Summary of findings throughout dissertation

The findings in this dissertation can be summarized briefly. First, the letter-as-percept view seems to be correct. Graphemic effects occur, but only late. Second, this plays out differently in Spanish and English. In Spanish, the units that are activated after letter perception are the syllable and abstract syllable structure, and this happens quickly. In English, the relevant unit is the grapheme, and this activation occurs slowly. Third, transfer of alphabetic processing knowledge seems to occur for adults in early stages of L2 development. This is informative, but not surprising. Whether that transfer is persistent or temporary is a more interesting question that will have to await future studies. Also, transfer in bilingual children was more difficult to find, which may have been a result of under-developed alphabetic processing knowledge in their L1. Fourth, young children show congruency effects, but the effects are relatively weak. Children who responded fastest showed tentative evidence for a letter-as-percept view.

CHAPTER 8 CONCLUSIONS

As previewed in the introductory chapter, this dissertation addressed how alphabetic writing systems are processed, how such processing knowledge applies cross-linguistically, and how early this knowledge can be tested using the masked-priming paradigm. This chapter attempts to associate the findings in this dissertation with broader issues. These issues are the psychological modeling of reading behavior, literacy development, and L2 acquisition.

8.1 The psychological modeling of reading

In the English-speaking world, at least, many people are familiar with the often acrimonious "Reading Wars" (see, for instance, Goodman, 2005; Rayner et al., 2001; Smith, 2004; Stanovich & Stanovich, 1999). But among psychologists, there is a quieter debate concerning exactly how to model the reading process in English, and other languages for that matter. Chapter 2 (Sections 2.3 and 2.4) reviewed part of this debate, which concerns how reading units are perceived at a basic level.

More specifically, this particular debate centers on the first abstract (mental) units that are formed in English after the analysis of visual features. In the letter-as-percept view, the primary units are letters, or contiguous graphic symbols. On the standard view, calculations would then be performed on letters to derive graphemes. Outside psychology, this view would probably be uncontroversial. In contrast, the grapheme-as-percept view holds that the primary abstract unit is the grapheme, bypassing (in a sense) the letter level altogether. Graphemes are letters and letter combinations that correspond to single phonemes (e.g., the EA in BREAD /brɛd/). The claim that the grapheme is the basic unit of visual word recognition revives an old hypothesis first put forward by Gibson and her colleagues in the early 1960s (Gibson, Osser, & Pick, 1963; Gibson et al., 1962).

The importance of this debate to psychological modeling should not be underestimated. Each model depends on a primary mental form. For instance, if it were to turn out that the grapheme was the basic reading unit, then Coltheart's dual-route cascaded model would have to be adapted or discarded if it could not adapt.

But instead, the findings in this dissertation challenges the revival of Gibson's hypothesis. The experiments here demonstrated that graphemes do play some sort of role in letter detection, but that role is not at the initial, perceptual level. The basic representation at the initial level seems to be the letter, akin to how it is currently modeled on the dual-route cascaded model.

This conclusion does not conflict with any model of alphabetic processing that has been proposed. There are no explicitly formulated word-recognition models that state that graphemes must be the basic reading unit. Even the strongest claims in the grapheme-as-percept view are tentative at this point. The closest any model comes to making the claim explicitly is Plaut et al's (1996) version of the parallel-distributed processing (PDP) network, though most advocates of this sort of network would claim that they are not at the point where they can make strong claims about the input units to the reading system. If the findings in this dissertation are correct, then all that can be said is that Plaut et al.'s (1996) version of the network is unsustainable. Models of word recognition must be based on abstract letters, not graphemes.

8.2 Literacy development

Just as there are debates among theorists who concentrate on reading models for proficient readers, there are debates about how children learn to read. And there is an important intersection between models of proficient reading and models of literacy development. This intersection has been fueled in the English-speaking world by the crisis in literacy education. English-speaking children learn to read in their L1 at considerably slower rates than their peers in other European orthographies (Harris & Hatano, 1999; Seymour, Aro, & Erskine, 2003). It comes as no surprise, therefore, that in the English-speaking world, scientists, educators, and government officials have attempted to fathom causes for the problems and remedies through science (e.g., National Institute of Child Health and Human Development, 2000; Rayner et al., 2001). Unsurprisingly, scientists have made suggestions to the teaching community regarding how best to teach reading. For instance, reading scientists have found over the last 20-30 years that phonology plays an important role in learning to read, and they have been quick to suggest (and rightly so, in my opinion) that instruction in the relationship between graphemes and phonemes needs to be emphasized in the classroom (National Institute of Child Health and Human Development, 2000; Rayner et al., 2001).

How might this dissertation inform reading instruction? Although whole-word instruction is already a bit of a pedagogical pariah to some because of the Reading Wars, the letter-as-percept view that is supported in this dissertation implies that this type of instruction might be pedagogically useful (more useful than many are probably willing to admit at this point). Indeed, in some tentative remarks about reading instruction, Jackson and Coltheart (2001) suggest that once children develop a strong foundation in abstract letter units, it will be easier for them to develop both graphemic representations (along the nonlexical route) and lexical representations (along the lexical route). Furthermore, development of the lexical route will contribute to development of the nonlexical route (and vice-versa, in fact). These entailments of dual-route-cascaded architecture lead them to suspect that whole-word instruction, which traditionally relies on letters and not graphemes, might play a useful, or even crucial, role in helping children learn to read.

But a grapheme-as-percept view might just reinforce the perhaps unwarranted aversion to letter-based whole-word instruction felt by some. Up until recently, it seemed that few, if any, literacy theorists questioned whether letters were basic to literacy development. For instance, Gibson and her colleagues had already seriously revised their grapheme-as-percept view by the 1970s (Gibson, Shurcliff, & Yonas, 1970), and many theorists have found that letter names, at least, can play a powerful role when children are just beginning to read (e.g., Bond & Dykstra, 1967; Foulin, 2005; Share, 2004). But again, as discussed extensively in Chapter 2, some theorists have recently suggested that graphemes may play a more basic role in literacy development. Plaut et al. (1996) discuss this sort of literacy development as a *fait accompli*. Ziegler and Goswami (2005) leave ample room for this sort of literacy development in their model. Rey et al. (2000) imply that letters are only temporary stepping stones to graphemic perception. These trends in the modeling of reading could lead to the premature dismissal of teaching methods based on letters, like whole-word instruction. Therefore, they should take seriously whether the basic reading unit is the letter or the grapheme. This dissertation suggests that it is the letter.

8.3 Second language acquisition

The study of transfer has a fairly long history in L2 acquisition, gaining speed about 50 years ago with the publication of Weinreich's *Languages in Contact* (1953), and Lado's *Linguistics Across Cultures* (1957). Odlin (2003) covers this history and the research foci of various transfer theorists. The research foci cover just about every conceivable area of language knowledge. But one of the younger research areas is language processing. The earliest studies in this domain that Odlin mentions are those by Sharwood-Smith (1979, 1986). And only recently have researchers begun to look at how orthographic-processing knowledge transfers across languages (e.g., Akamatsu, 1999, 2003; Gesi Blanchard, 1998; Geva, Wade-Woolley, & Shany, 1997; Koda, 1989, 1990, 1995; Nassaji & Geva, 1999; Taft, 2002).

For adults and children learning an L2 "as a foreign language" (i.e., in an environment where the L1 is dominant in society), the effects of orthographic-processing transfer are probably trivial in most cases. Such learners are usually under no great pressure to perform in their L2. But if they are learning their L2 "as a second language" (i.e., in an environment where the L2 is dominant in society), then transfer issues can be more important. Performance in the L2 can be critical. This is currently the case with many Spanish-dominant bilingual children in the US.

According to the US Census Bureau (2003), the number of people in Spanish-speaking homes increased 62% from 1990 to 2000. The 2003 brief reports that over seven million Spanish-speakers speak no English or speak it poorly. Considering all languages, the same census found that 12 million people are “linguistically isolated” (i.e., in households where no one over 14 speaks English “very well”). This number was significantly greater in 2000 than in 1990. This implies that more and more Spanish-dominant children are entering US school systems.

Many researchers have argued that, if possible, a child who is weak in her L2 should be taught in her L1, at least in the beginning. They claim that this is preferable to educating her in her L2. This includes teaching her how to read in her L1 (Bialystok, 2001; Cummins, 1984; Grosjean, 1982; MacNamara, 1966). This makes a great deal of intuitive sense. If the child cannot understand the medium of instruction, then she will almost certainly fall behind. But at the same time, the child must learn to read in her L2 in order to learn in that language. Solutions to this vary, but the dominant recommendation is transitional bilingual education, where children are educated in their L1 while developing L2 skills (Bialystok, 2001; Brisk, 1998). When their L2 skills are strong enough to allow them to participate in monolingual, L2 classrooms (the dominant classroom type in that society), then they are “transitioned” over to those classes. Although this approach has been criticized as an inherently defective approach to promoting bilingualism (e.g., Hakuta & Mostafapour, 1996), it seems workable in the best case scenario.

But there may be consequences to teaching a child to read in her L1 that may affect how she learns to read in her L2 (or vice-versa). This may be problematic if the two languages share letters, as English and Spanish do. It may take some time before child learning to read Spanish and English can fully understand that a given letter may mean two different things depending on the language. Referring again to the focus of this dissertation, double vowels in Spanish always refer to two phonemes, whereas double vowels in English most often (but not always) refer to one phoneme. Such cross-linguistic differences must necessarily add complexity to the learning task, something which children in an L2 environment can ill afford.

Overall, very little research examines alphabetic transfer among young, developing bilinguals (Durgunoğlu & Hancin, 1992; Geva & Siegel, 2000). We are only beginning to find ways to study cross-linguistic reading processes in children. This dissertation is an early step in that direction, and provides some valuable insights in how to take this line of research further.

APPENDIX A. Low-frequency items from adult Spanish experiment.

	YES Responses				NO Responses			
Search Letter	Primes			Target	Primes			Target
	Single Vowel	Double Vowel	Control		Single Vowel	Double Vowel	Control	
	pastel	gaucho	lumbre	CASERO	brocal	ferial	cordel	CURSOR
	surcar	**bucear**	**reptil**	**POSTAL**	**trasto**	**loable**	**oyente**	**BROCHE**
	roncar	copiar	doblez	BELDAD	clamor	realce	inerte	TROPEL
	tentar	**espiar**	**crisol**	**FLORAL**	**impago**	**oleaje**	**harina**	**GEMELO**
A	lapsus	caucho	copete	FARDEL	metate	decaer	penoso	IMPURO
	evadir	**fraude**	**exigir**	**TRANCO**	**orador**	**piafar**	**inerme**	**EXENTO**
	grupal	boxear	crujir	DISPAR	charol	reacio	oponer	CHISME
	rebatir	**incauto**	**vidente**	**ESTANCO**	**granito**	**fiambre**	**brindis**	**EMERGER**
	invasor	recaudo	diferir	ESTANTE	mutante	mosaico	inculto	OPRESOR
	rector	**deudor**	**fogoso**	**SERVIL**	**tipejo**	**irreal**	**lozano**	**ALTIVO**
	verdor	deidad	masiva	RECATO	adepto	faenar	acusar	PRIMOR
	acervo	**cuervo**	**trompo**	**PLEGAR**	**pretil**	**creido**	**brizna**	**AZOTAR**
	fregar	tuerto	adicto	FLECHA	melosa	meollo	dulzor	SACRAL
E	**acelga**	**huelga**	**grabar**	**INEPTO**	**cegato**	**feudal**	**librar**	**POROSO**
	cresta	hiedra	franja	APELAR	fijeza	proeza	obtusa	GARETE*
	damero	**trueno**	**insano**	**VIVEZA**	**conejo**	**gotear**	**nuboso**	**FISURA**
	frenazo	fieltro	prolijo	ATENTAR	frescor	miedoso	fruncir	PLATINO
	lechuza	**teorema**	**halagar**	**FESTIVO**	**cosecha**	**alienar**	**monacal**	**TUMULTO**
	tijera	lienzo	reseco	DICTAR	jinete	airoso	burlar	DENTAL
	mimbre	**cierva**	**bonete**	**PILLAR**	**filtro**	**diurno**	**fardar**	**CEREZO**
	firmar	fierro	demora	PINCEL	ovillo	axioma	alegar	FRUTAL
	virrey	**siervo**	**lustre**	**HINCAR**	**abisal**	**ocioso**	**franco**	**EMULAR**
I	opinar	peinar	ofensa	GRILLO	hocico	enviar	galera	ANTOJO
	editor	**guisar**	**traste**	**OJIVAL**	**levita**	**mediar**	**tutela**	**PECOSO**
	editar	grieta	frenar	BRINCO	marfil	mustio	vengar	HERVOR
	pepsina	**deleite**	**desmayo**	**MESTIZO**	**jeringa**	**rabieta**	**arbusto**	**DECORAR**
	nulidad	estiaje	arrullo	DECIMAL	exitoso	amianto	exaltar	CRUCERO
	gusano	**puerco**	**fineza**	**SUPLIR**	**astuto**	**flauta**	**jirafa**	**ESBOZO**
	nutrir	pueril	bordar	MULETA	desuso	casual	boceto	ISLOTE
	lujoso	**suegro**	**medrar**	**TULIPA**	**minuta**	**intuir**	**espiga**	**COYOTE**
	culpar	vuelco	carril	RUDEZA	jugoso	juerga	melaza	DORSAL
U	**rugoso**	**luengo**	**casino**	**TUMBAR**	**lisura**	**tatuar**	**arrimo**	**MOHOSO**
	zumbar	cuenco	forzar	RUGIDO	finura	locuaz	felino	PEGOTE
	mulato	**muermo**	**faceta**	**CUNDIR**	**butano**	**buitre**	**fabril**	**DESLIZ**
	efusivo	apuesto	asidero	TRUCAJE	brumoso	neurona	erizado	CLAVIJO
	verdura	**graduar**	**despojo**	**RECLUTA**	**repunte**	**genuino**	**escolar**	**DEVENIR**

APPENDIX B. High-frequency items from adult Spanish experiment.

Search Letter	YES Responses				NO Responses			
	Primes			Target	Primes			Target
	Single Vowel	Double Vowel	Control		Single Vowel	Double Vowel	Control	
	flanco	fiable	elixir	LLAMAR	granel	viable	elenco	BRILLO
A	**cactus**	**naipes**	**corcel**	**HAMBRE**	**pugnaz**	**cocear**	**hervir**	**TERROR**
	levante	donaire	docente	MILAGRO	trasluz	piadoso	cretino	ENEMIGO
	sensor	**neutro**	**rancho**	**MEZCLA**	**gotera**	**hojear**	**gorila**	**FAMOSO**
E	avenir	ciervo	asiduo	PRENSA	salero	pliego	caduco	VISITA
	cotejar	**cruenta**	**cizalla**	**BOTELLA**	**letrado**	**neutral**	**finitud**	**CAPITAL**
	torcido	fluvial	enchufe	MENTIRA	cerviz	abulia	forjar	TERCER
I	**millar**	**rienda**	**rotura**	**VIRTUD**	**aludir**	**rancio**	**rondar**	**LECTOR**
	hilera	hiatos	conque	BIGOTE	emigrar	taimado	frutero	APARATO
	fundir	**cuerno**	**calzar**	**RUTINA**	**ducado**	**duende**	**salino**	**VIRGEN**
U	sumiso	cuerdo	racimo	VULGAR	gamuza	secuaz	cadera	RELATO
	inmundo	**escueto**	**escoplo**	**COLUMNA**	**tribuna**	**aplauso**	**drenaje**	**CARRERA**

APPENDIX C. Instructions to adult participants.

Spanish

Presione cualquier botón con el pulgar de la mano derecha para pasar de pantalla a pantalla.
Primero verá una sola letra mayúscula. Por ejemplo - A
Esta es la letra que tendrá que identificar.
Luego verá una serie de símbolos (#####). Uno de ellos aparecerá en un color diferente.
Mantenga sus ojos en el símbolo del color diferente.
A continuación aparecerá una palabra inglesa en letra mayúscula. Por ejemplo - LUSTRE.
Presione el botón de SÍ si ve la letra que apareció al principio en esta palabra.
El botón de SÍ es el de la derecha donde está su dedo índice.
Presione el botón de NO si no ve la letra que apareció al principio en esta palabra.
El botón de NO es el de la izquierda donde está su dedo índice.
Responda en el menor tiempo posible, siempre procurando evitar errores.
Pero siempre se esperan algunos errores. La rapidez es más importante que la precisión.
Luego de que aparezca una pantalla en blanco, verá el siguiente ítem automáticamente.
En cada una de las 4 listas, tendrá que identificar una letra en particular.
Las letras que se presentarán son la A, E, I, y U, respectivamente.
Después de cada lista, el programa esperará su orden para continuar.
Tendrá que presionar cualquier botón con el pulgar para empezar con la próxima lista.
Los siguientes ítems son de práctica. La letra a identificar es la A.

English

Press any button with your right thumb to go from screen to screen.
First you will see a letter in uppercase. For example - A.
This is the letter that you will identify.
Next you will see a row of symbols (#####). One of them will be colored differently.
Fixate your eyes on the one that is colored differently.
Next you will see a word in uppercase letters. For example - CLAMP.
Press the YES button if you saw the letter you are supposed to identify.
The YES button is the one under your right index finger.
Press the NO button if you did not see the letter you are supposed to identify.
The NO button is the one under your left index finger.
Try to respond as quickly as possible, but not so fast that you start making lots of errors.
But a few errors are expected. Speed is more important than accuracy.
After you respond, the screen will go blank and the next item will appear automatically.
In each of the four lists, you will identify one particular letter.
The letters that will be presented in each list are A, E, I, and U, respectively.
Between each letter group the computer will wait for you to tell it to continue.
Just press any button with your right thumb to continue.
The following items are for practice. The letter to identify is A.

APPENDIX D. Low-frequency items from adult English experiment.

Search Letter	YES Responses				NO Responses			
	Primes			Target	Primes			Target
	Single Vowel	Double Vowel	Control		Single Vowel	Double Vowel	Control	
	slash	peach	blink	GRAFT	shack	beast	brunt	FLIRT
	clash	**leash**	**plumb**	**TRACT**	**chant**	**boast**	**fling**	**SNIFF**
	stamp	pearl	grill	BRASH	shank	yeast	fluff	TRILL
	chalk	**snail**	**skull**	**TRASH**	**swamp**	**toast**	**chick**	**PLUSH**
A	bland	flail	clump	STARK	brazen	beaver	enigma	TRENCH
	tramp	**trait**	**grunt**	**SLACK**	**tyrant**	**crease**	**onrush**	**DIVEST**
	inland	impair	govern	FORAGE	trance	hoarse	crunch	BLIGHT
	dragon	**beaker**	**acumen**	**SPARSE**	**starve**	**hearse**	**scurvy**	**BRIDLE**
	fathom	raisin	mingle	GADGET	candid	caucus	behold	MUTINY
	chess	**cheer**	**traps**	**SPECK**	**knelt**	**plead**	**slant**	**TRUNK**
	dwell	greed	swarm	THEFT	blend	creed	smack	STUNT
	tenth	**reign**	**burnt**	**WELSH**	**hyena**	**creak**	**snack**	**WRING**
	wreck	tweed	flask	SMELT	wrest	steam	blitz	BLAST
E	**divert**	**upbeat**	**disarm**	**CARESS**	**offend**	**ordeal**	**modify**	**THRUSH**
	infest	afield	splash	TAVERN	shrewd	shield	insult	WIZARD
	clench	**woeful**	**sludge**	**TREMOR**	**scenic**	**sheath**	**alight**	**TROPHY**
	mellow	neural	pickle	LEGACY	detach	dearth	wiggle	MORBID
	stench	**breach**	**clinch**	**CHERRY**	**wretch**	**wreath**	**stupor**	**FRIGID**
	whirl	taint	brawl	SKIMP	shrink	lesion	afresh	DEMURE
	crisp	**saint**	**brand**	**WHISK**	**docile**	**legion**	**delude**	**TENANT**
	drift	moist	grasp	SPILL	stint	waist	stall	TRUMP
	print	**reins**	**blank**	**SLICK**	**unify**	**weird**	**gruff**	**CRASS**
I	girth	wield	sever	HITCH	rustic	ordain	donkey	LAWFUL
	bandit	**deceit**	**possum**	**FORBID**	**adrift**	**option**	**onward**	**COVERT**
	sinful	diesel	burrow	DILATE	flimsy	maiden	agenda	ORATOR
	garlic	**recoil**	**walrus**	**FLORID**	**tonsil**	**assail**	**asylum**	**SHOVEL**
	banish	cruise	tomato	PACIFY	depict	shriek	dosage	SOLEMN
	thumb	**hound**	**skiff**	**PLUCK**	**blush**	**druid**	**swirl**	**PRANK**
	plump	taunt	knack	CRUST	blunt	mound	wharf	SHELF
	strut	**trout**	**flyer**	**SHRUB**	**crush**	**couch**	**swell**	**GLINT**
	scrub	clout	toxic	SHRUG	bunch	dumps	focal	MIRTH
U	**chuck**	**cruel**	**champ**	**FLUSH**	**thump**	**pouch**	**smash**	**GRIST**
	dilute	spouse	levity	NEBULA	consul	devour	floral	MATRIX
	plunge	**bruise**	**amidst**	**CRUTCH**	**punish**	**outlaw**	**mentor**	**CANOPY**
	citrus	sprout	myopic	EYEFUL	ambush	abound	notify	INVERT
	amulet	**faucet**	**tripod**	**GRUDGE**	**ocular**	**bounty**	**frenzy**	**ELAPSE**

APPENDIX E. High-frequency items from adult English experiment.

Search Letter	YES Responses: Primes: Single Vowel	YES Responses: Primes: Double Vowel	YES Responses: Primes: Control	YES Responses: Target	NO Responses: Primes: Single Vowel	NO Responses: Primes: Double Vowel	NO Responses: Primes: Control	NO Responses: Target
	enamel	weasel	edible	STATUS	yacht	haunt	mulch	COLOR
A	**global**	**uproar**	**frolic**	**NORMAL**	**harsh**	**daunt**	**munch**	**MONTH**
	backs	gaunt	midst	TABLE	runway	repeal	folder	WINDOW
	spell	**steep**	**brass**	**FLESH**	**hectic**	**hearth**	**funnel**	**BOTTOM**
E	shred	kneel	sprig	LOWER	fleck	knead	psalm	STORY
	befall	**zealot**	**burger**	**RECORD**	**fetch**	**weigh**	**ninth**	**BASIS**
	whiff	thief	wrack	BRING	fiddle	pierce	harden	DOCTOR
I	**demise**	**facial**	**depart**	**DESIGN**	**brink**	**grief**	**swath**	**EVENT**
	unison	dainty	ocelot	EDITOR	flint	hoist	scalp	CHECK
	chunk	**joust**	**flick**	**TRULY**	**spurt**	**vault**	**smirk**	**STAND**
U	rotund	slouch	ascent	RESULT	pulpit	outlet	ballad	MEMBER
	nugget	**suitor**	**piracy**	**SUPPLY**	**flurry**	**causal**	**thesis**	**BRIDGE**

APPENDIX F. Items from replication of Rey et al’s (2000) experiment 1A.

YES responses									
Frequency									
High				Low					
Single vowel		Vowel digraph		Single vowel		Vowel digraph		Split digraph	
Search letter	Target	Search letter	Target	Search letter	Target	Search letter	Target	Search letter	Target
A	class	A	reach	A	stark	A	peach	A	blaze
A	**black**	**A**	**learn**	**A**	**tract**	**A**	**yearn**	**A**	**flake**
A	grass	A	clear	A	slack	A	bleak	A	slate
A	**glass**	**A**	**teach**	**A**	**graft**	**A**	**leach**	**A**	**graze**
A	track	A	coast	A	trash	A	poach	A	crate
A	**staff**	**A**	**board**	**A**	**brash**	**A**	**hoard**	**A**	**snare**
E	dress	E	chief	E	speck	E	grief	I	shine
E	**press**	**E**	**field**	**E**	**theft**	**E**	**wield**	**I**	**slice**
I	bring	I	paint	I	skimp	I	snail	I	bribe
I	**stick**	**I**	**chain**	**I**	**whisk**	**I**	**broil**	**I**	**chive**
I	shift	I	joint	I	spill	I	stain	I	glide
I	**skill**	**I**	**trail**	**I**	**slick**	**I**	**hoist**	**I**	**spine**
U	trust	U	count	U	pluck	U	vault	U	flute
U	**truth**	**U**	**mouth**	**U**	**crumb**	**U**	**mourn**	**U**	**truce**
U	stuff	U	youth	U	snuff	U	taunt	U	prune
NO responses									
A	**bench**	**A**	**spoil**	**E**	**proof**	**I**	**straw**	**U**	**flesh**
A	brick	A	steel	E	smart	I	wheat	U	sling
A	**brush**	**A**	**stiff**	**E**	**blind**	**I**	**worst**	**U**	**phone**
A	chest	A	tribe	E	bunch	I	stuck	U	bride
A	**cloth**	**A**	**trout**	**E**	**crush**	**I**	**flock**	**U**	**chill**
A	crude	A	truck	E	drain	I	quest	U	depth
A	**ghost**	**A**	**twist**	**E**	**round**	**I**	**beard**	**U**	**faint**
A	grind	A	weigh	E	squad	I	beast	U	fence
A	**kneel**	**A**	**witch**	**E**	**saint**	**I**	**cease**	**U**	**frown**
A	lodge	A	clerk	E	shock	I	false	U	pride
A	**sheer**	**A**	**cross**	**I**	**shade**	**I**	**flame**	**U**	**cling**
A	shore	A	greed	I	skull	I	found	U	skirt
A	**climb**	**A**	**trick**	**I**	**snake**	**I**	**gleam**	**U**	**spell**
A	slope	E	drift	I	spare	I	phase	U	sport
A	**split**	**E**	**pitch**	**I**	**spray**	**U**	**brave**	**U**	**waist**

APPENDIX G. Instructions from replication of Rey et al's (2000) experiment 1A.

Press the footpedal to go from screen to screen

First you will see a letter in uppercase.

For example - A

Next you will see a word in lowercase letters.

For example - clamp

Press the YES button if you saw the letter you are supposed to identify.

Press the NO button if you did NOT see the letter you are supposed to identify.

Try to respond as quickly as possible, but not so fast that you start making lots of errors.

After you respond the screen will go blank and the next item will appear automatically.

The following items are for practice.

The letter to identify is A.

APPENDIX H. Items from children's experiment.

	YES responses				NO responses			
	Primes			Target	Primes			Target
	Single vowel	Double vowel	Control		Single vowel	Double vowel	Control	
	happy	daily	fight	WAGON	party	early	light	DEPTH
	march	**faith**	**worry**	**TASTE**	**royal**	**dream**	**owner**	**PILOT**
	glass	trail	clerk	SHARP	scale	learn	spend	DRINK
	share	**heavy**	**cloth**	**GRASS**	**legal**	**break**	**mixed**	**THROW**
A	sugar	clean	offer	METAL	crazy	coast	trend	EXIST
	mental	**throat**	**pocket**	**DOLLAR**	**shadow**	**search**	**useful**	**CRISIS**
	status	health	proper	CHARGE	remark	strain	engine	SEVERE
	recall	**remain**	**corner**	**ISLAND**	**debate**	**obtain**	**minute**	**NOBODY**
	impact	steady	memory	ESCAPE	glance	weapon	energy	SWITCH
	bench	**beach**	**birth**	**REPLY**	**agent**	**ocean**	**shock**	**TRUST**
	smell	ideal	grand	CHEST	cover	chief	prior	URBAN
	dress	**bread**	**gross**	**CHECK**	**swept**	**clear**	**track**	**SKILL**
	spent	speak	swift	ALERT	below	teach	watch	SIGHT
E	**press**	**yield**	**crowd**	**FRESH**	**length**	**season**	**narrow**	**FINISH**
	panel	brief	allow	NOVEL	forest	appear	trying	STRUCK
	comedy	**stream**	**policy**	**OBJECT**	**talent**	**threat**	**living**	**STRONG**
	pretty	theory	prison	CREDIT	belong	nearby	harbor	WISDOM
	accept	**friend**	**afford**	**HONEST**	**agency**	**breath**	**branch**	**ORIGIN**
	bride	noise	frame	STICK	price	paint	shape	BLOCK
	blind	**joint**	**blame**	**PRIDE**	**thick**	**built**	**grave**	**STORE**
	solid	avoid	error	MAGIC	rapid	fruit	mayor	MODEL
	begin	**chair**	**dozen**	**ADMIT**	**basic**	**chain**	**major**	**HOTEL**
I	final	field	moral	RIVER	atomic	detail	secret	FORMAL
	basis	**train**	**paper**	**UNTIL**	**permit**	**cousin***	**output**	**ANSWER**
	tragic	affair	suffer	PENCIL	device	motion	remote	SALARY
	design	**region**	**excess**	**ACTIVE**	**desire**	**junior**	**almost**	**DEPEND**
	decide	belief	reduce	ARTIST	notice	relief	stress	ATTACK
	judge	**build**	**catch**	**LUNCH**	**curve**	**outer**	**waste**	**DIRTY**
	stuff	count	knife	TRUTH	brush	round	shift	THANK
	occur	**proud**	**enjoy**	**FOCUS**	**swung**	**youth**	**snake**	**DRILL**
	truck	cause	known	STUDY	begun	value	armed	MINOR
U	**rural**	**quick**	**porch**	**FUNNY**	**campus**	**tissue**	**dinner**	**FOLLOW**
	burst	guest	local	HUMAN	nature	ground	always	EFFECT
	hurry	**guess**	**woman**	**MUSIC**	**church**	**source**	**plenty**	**TRAVEL**
	burden	author	random	LUMBER	column	visual	family	EXTEND
	result	**amount**	**modern**	**FIGURE**	**return**	**actual**	**recent**	**ENTIRE**

APPENDIX I. Script from orientation to children's experiment.

Hi/[Hola] (NAME)

We're going to play a word game today. You are going to look at English words and decide if you see certain letters in them. Let's practice on these cards. You're going to see a letter on each of these cards. Look at it and just memorize it; don't say it out loud. When I turn the card over, tell me YES or NO if the letter is in the word.

[Hoy vamos a jugar un juego de palabras. Vas a ver unas palabras en inglés y me tenés que decir si ves algunas letras en las palabras. Vamos a practicar con estas tarjetitas. Vas a ver una letra en cada una de estas tarjetitas. Mirá la letra atentamente y memorizala, pero no la digas en voz alta. Cuando dé vuelta la tarjetita, decime si ves la letra. Decime SI si las ves o NO si no la ves.]

The test giver briefly shows the participant the letter printed on one side of on the card. He turns it over and lets her say YES or NO. He continues 5 times to make sure that the participant gets the right answer 4 out of 5 times. If not, he gives her an easier version of the computer task (in fact, this never happened)

Good! Now we're going to do this on a computer. Have you used one of these before?

[¡Muy bien! Ahora vamos a hacerlo en la computadora. ¿Has usado alguna vez uno de estos?]

The test giver shows the participant the game controller. He demonstrate how it works. He then shows the participant that she only needs to use the two index-finger buttons.

Now we're going to do the same thing with words on a computer screen. The first thing you will see is the letter you need to find. This could be an A, an E, an I, or a U.

[Ahora vamos a hacer lo mismo con otras palabras en la pantalla de la computadora. Lo primero que vas a ver es la letra que tenés que encontrar. Esta letra puede ser la A, la E, la I o la U.]

The test giver shows the participant the demonstration letter A on the screen.

This will be on the screen for about a half second. Remember the letter. This won't be very hard because all the A's will be together. Same with the E's, the I's, and the U's. The letter will disappear, and the next thing you will see is a bunch of symbols like this

[Esta letra va a aparecer en la pantalla por más o menos medio segundo. No te olvides de esta letra. No va a ser difícil porque todas las As aparecen juntas. Lo mismo va a pasar con la E, la I y la U. La letra va a desaparecer y lo que vas a ver va a ser una serie de símbolos como este.]

The test giver shows the participant the example hashmarks on the computer screen.

Notice how one of them is colored differently? When they come up on the screen, keep your eyes on this differently colored symbol. These symbols will also be on the screen for about a half second.

[¿Ves que uno de los símbolos es de color diferente? Cuando aparezcan, tenés que mirar atentamente este símbolo. Los símbolos van a estar en la pantalla por medio segundo.]

The test giver brings up the next screen (corresponding to the target)

Now you will see is a word in all capital letters in the center of the screen. Just like we did with the cards, you need to decide whether or not the letter you just saw all alone is in the word too. The YES button is on the right, and the NO button is on the left. You press the right button if the letter is in the word, and you press the left button if the letter is not in the word. You do this as fast as possible, but not so fast that you make a lot of mistakes. There is also a green plus symbol on the right-hand side. This is just to remind you that the right button means YES. On the left, the red minus symbol is there to remind you that the left button means NO. Mistakes are okay. Want to practice?

[Ahora vas a ver una palabra en letras mayúsculas en el centro de la pantalla. Como lo hicimos con las tarjetitas, tenés que decidir si la letra que acabás de ver sola está en la palabra. El botón de SI está a la derecha y el botón para NO está a la izquierda. Entonces presionás el botón de SI a la derecha si la letra está en la palabra, y presionás el botón de NO a la izquierda si la letra no está en la palabra. Tenés que tratar de hacer esto lo más rápido que puedas, pero no tan rápido que te equivoques. Podés ver en la pantalla que hay un signo de más en verde en el lado derecho. Este signo te recuerda que el botón de la derecha significa SI. Del lado izquierdo, el signo de menos en rojo te recuerda que el botón de la izquierda significa NO. Si hacés un error está bien, no hay problema. ¿Querés practicar?]

The participant completes 15 practice items. If she misses more than 5, the test giver gives her an easier version of the experimental task (in fact, this never happened).

You've done really well. I think you're ready to do the activity all by yourself. What do you think? Do you still want to continue? Remember, you don't have to. Do you have any questions? If not, go ahead and start.

[¡Muy bien! Creo que estás listo/a para hacer la actividad solito/a. ¿Te parece? ¿Todavía querés continuar? Acordate que no tenés que hacerlo si no querés. ¿Tenés alguna pregunta? Si no tenés ninguna, empezá la actividad.]

The participant starts the task.

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