

2026

Multimodal assessment of alexia in bilinguals with aphasia

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BOSTON UNIVERSITY
SARGENT COLLEGE OF HEALTH AND REHABILITATION SCIENCES

Dissertation

**MULTIMODAL ASSESSMENT OF ALEXIA
IN BILINGUALS WITH APHASIA**

by

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Submitted in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

2026

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ABSTRACT

Spanish–English bilinguals with aphasia (BWA) frequently present with alexia, an acquired reading disorder that reflects disruption to shared linguistic systems shaped by bilingual experience. This dissertation integrates clinical assessment and eye-tracking measures to characterize reading impairment in BWA and to examine how lexical and contextual information are recruited during online sentence comprehension following stroke. Aim 1 examined oral reading and reading comprehension in Spanish and English to characterize the presence and severity of reading impairment in aphasia and to diagnose acquired dyslexia subtypes in 11 BWA and 20 English-speaking monolingual adults with aphasia (MWA). Across groups, reading impairment was robust for the aphasia groups relative to controls and patterned similarly in bilingual and monolingual individuals. Analyses further evaluated the relationship between spoken and written language processing, revealing phonological ability as the strongest predictor of oral reading accuracy and semantic ability as a more selective predictor of reading comprehension. In BWA, additional analyses of cross-language similarity effects indicated preserved non-selective activation during reading, consistent with disruption to shared semantic–

phonological systems rather than language-specific reading mechanisms. Aim 2 used eye tracking to examine real-time sentence reading under varying levels of semantic constraint across four groups: 16 MWA, 20 English-speaking monolingual neurological controls (MNC), 8 BWA, and 10 bilingual neurological controls (BNC). Eye-movement measures revealed aphasia-related disruptions that were expressed during early-stage and late-stage processing in the MWA but only reliably during later stages of processing for the BWA. In bilingual aphasia, lexical phenomena such as cognate facilitation and homograph interference were observed but strongly context dependent and emerged primarily as delayed or distributed costs during sentence-level integration. Together, these findings demonstrate that alexia in bilingual aphasia reflects disruption to shared linguistic systems that parallels monolingual aphasia, while remaining shaped by bilingual experience and task demands. The results underscore the value of multimodal assessment for informing theory and clinical evaluation.

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LIST OF ABBREVIATIONS

BIA+: Bilingual Interactive Activation Plus

BIAA: Bilingual Interactive Activation for Aphasia

BNC: Bilingual neurological controls

BWA: Bilinguals with aphasia

DRC: Dual-route cascaded

ENC: Eye tracking norming controls

FFD: First fixation duration

GD: Gaze Duration

GLMM: Generalized linear mixed model

GPD: Go-past Duration

HC: Healthy controls

IA: Interest area

LIDH: Lexical Integration Deficit Hypothesis

LMM: Linear mixed model

MNC: Monolingual neurological controls

MoCA: Montreal Cognitive Assessment

MWA: Monolinguals with aphasia

NABW: No Aphasia by WAB

ODH: Orthographic Depth Hypothesis

PDP: Parallel distributed processing

PWA: People/Persons with aphasia

RRD: Rereading Duration

SD: Standard deviation

WAB-R AQ: Western Aphasia Battery-Revised Aphasia Quotient

1. INTRODUCTION

Approximately 2 million individuals living in the United States have aphasia (Flowers et al., 2016; Virani et al., 2021), a language disorder that typically results in pervasive difficulties in functional communication and long-term negative consequences for social participation (Azios et al., 2022) vocational independence, and overall health and quality of life (Bullier et al., 2020). In the coming years, the number of bilingual individuals living with aphasia is expected to rise (Rodriguez et al., 2014) due to demographic factors such as migration favoring increased multilingualism and multiculturalism and epidemiological trends pointing to an uptick in stroke incidence (Centeno, 2008) especially among individuals who identify as members of racial-ethnic minority groups (e.g., Hispanic individuals; Centeno, 2009; Scimeca et al., 2022). Although there has been a steady increase in the number of studies that have investigated bilingual aphasia in recent decades (Goral, 2023; Kuzmina et al., 2019; Lee & Faroqi-Shah, 2024; Peñaloza & Kiran, 2019) few have focused on written language (i.e., reading and writing; Cuetos & Centeno, 2009; Goral, 2019). This trend is concerning because bilinguals with aphasia (BWA), especially Spanish-English adults, are expected to seek more specialized rehabilitation services for acquired reading disorders in the coming years. Unfortunately, Spanish-English BWA may struggle to find high quality assessment and treatment opportunities for several reasons.

First, previous studies in bilingual aphasia have predominately focused on the rehabilitation of spoken word retrieval deficits post-stroke (Lee & Faroqi-Shah, 2024),

resulting in few evidence-based resources for evaluating reading impairment or prescribing treatment, especially in more than one language. The lack of bilingual-specific information about post-stroke reading is particularly concerning given how often persons with aphasia (PWA) report difficulties decoding and comprehending sentences and longer texts following a stroke (Hux et al., 2020; Wallace et al., 2019; Webster et al., 2018; Webster et al., 2021). Indeed, longer processing times associated with reading impairment make reading less enjoyable and lead many PWA to avoid or abandon reading activities altogether. Crucially, however, PWA remain interested in literacy after stroke (Kjellén et al., 2017) and routinely seek language therapy to ameliorate reading difficulties (Knollman-Porter et al., 2015; Knollman-Porter & Julian, 2019). Nevertheless, it is unclear how these trends might differ for BWA who may contend with difficulties in both languages.

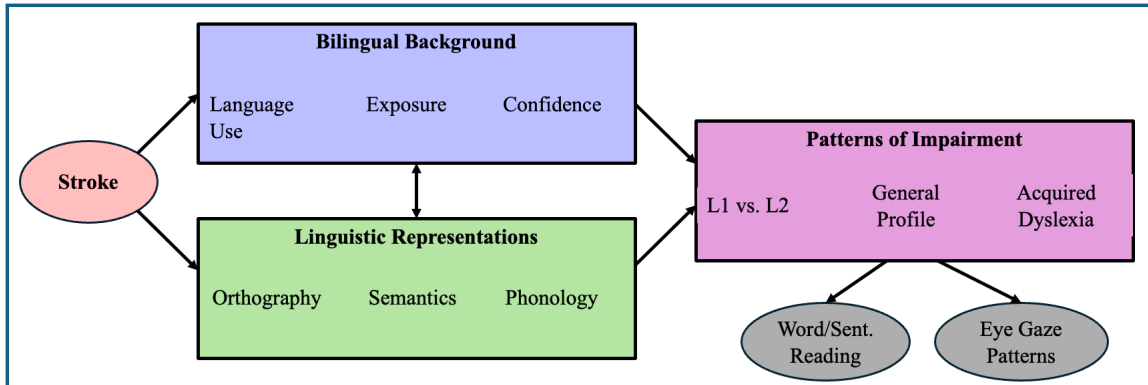
Second, the sparse body of literature in reading and bilingual aphasia is based almost entirely on single cases and studies with small samples that make it difficult to generalize findings to a population as heterogeneous as BWA. Furthermore, many open questions about the nature of written language processing after stroke persist. For example, recent research suggests that reading impairment is possible in both languages and that language-specific orthographies may affect post-stroke reading, especially during single word tasks (Goral, 2019). However, it remains unclear to what extent differences in profiles of acquired dyslexia (e.g., phonological vs. surface dyslexia) and differences in the magnitude of impairment should be expected between languages.

Third, the current literature lacks research on how BWA navigate reading in real-time post-stroke which obscures our understanding of how bilingual individuals confront challenges in reading in their daily life including the struggles they encounter and any strategies they might use to mitigate reading difficulties. While it is known that aphasia impairs access to semantic, phonological, and orthographic representations necessary for reading, its specific impact on post-stroke reading for bilingual individuals remains unexplored. In the PWA literature, several studies have used a combination of clinical and eye tracking methods to reveal how word-level factors and sentence structure influence incremental processing—as meaning unfolds over time—during silent reading comprehension. These studies have also examined how these factors contribute to comprehension breakdowns in real-time (for a review, see Sharma et al., 2021). Crucially, there are eye tracking studies with healthy bilinguals that have revealed how word-level factors and sentence structure also explain silent reading comprehension in the context of language co-activation (given that both languages are engaged to some extent during bilingual reading). But at present, no studies have used similar methods to examine reading behavior among BWA. Therefore, the current literature does not address how offline and online measures of post-stroke reading ability may be combined to improve our understanding of the complex relationships between single word and written sentence level processing in bilingual aphasia.

Given this background, the overarching goals of this dissertation work are to investigate post-stroke patterns of acquired reading disorders in Spanish-English BWA. The foundation and organizing framework for this work is illustrated in Figure 1.1 which

demonstrates hypothesized relationships between stroke damage, bilingual background characteristics (i.e., reading proficiency), linguistic representations, and post-stroke patterns of impairment.

Figure 1.1 Framework for Dissertation Work



Caption. A schematic illustrating the primary motivation for the dissertation proposal. Stroke damages linguistic representations and alters bilingual background characteristics at a single point in time. Changes to bilingual background and linguistic representations form a feedback loop that give rise to patterns of impairment over time. Post-stroke impairment can be measured via offline tasks and online tasks such as oral reading and reading comprehension tasks as well as eye gaze patterns during reading during eye tracking.

First, linguistic representations in bilingual individuals are learned over time and are tuned according to bilingual background characteristics such as the frequency of reading (i.e., language use), exposure to reading across the lifespan, and fluctuations in confidence or feelings about self-efficacy in both languages. Crucially, the strength of orthographic, semantic, and phonological representations and the connections between them can shift across the lifespan due to changes in reading habits and/or bilingual background. When a bilingual individual experiences a stroke, language deficits arise directly from damage to these representations and indirectly from changes to language use, exposure, and confidence characteristics. For example, severe reading impairment in one

language could reduce an individual's confidence and encourage them to avoid reading in that language. Patterns of impairment, or reading difficulties between languages, arise from this interaction between bilingual background and linguistic representations. Overall, BWA may demonstrate patterns of post-stroke deficits that may vary according to their language learning, a general profile of bilingual impairment, and specific subtypes of acquired dyslexia. In this dissertation work, this variation in patterns of impairment was measured via offline clinical measures of reading at the single word and sentence levels and online measures of eye gaze using eye tracking. More specifically, Aim 1 examined profiles of alexia and acquired dyslexia in BWA and English-speaking monolinguals with aphasia (MWA) by analyzing performance on offline clinical measures of reading ability in English and Spanish. Aim 2 used eye tracking during sentence reading to characterize the time course of online comprehension in aphasia and to examine how linguistic context and lexical properties shape reading behavior in bilingual and monolingual readers post-stroke. Together these aims allowed us to map the contours of alexia in BWA and provided a foundation for developing future approaches to supporting bilingual individuals in their reading recovery goals post-stroke.

The background to support these aims—in addition to the implications of the framework in Figure 1.1—will be emphasized throughout the remainder of this work which is organized as follows: Chapter 2 will introduce general psycholinguistic models of reading and how damage to linguistic representations leads to reading impairment. Chapter 3 will review the evidence for the differences in clinical profiles of alexia and acquired dyslexia in MWA and BWA. Chapter 4 will present evidence for using eye tracking to

examine real-time reading comprehension in aphasia, with implications for similar analyses in BWA. Chapter 5 will provide the final background necessary for the aims and hypotheses by introducing bilingual specific mechanisms of written language processing. Then, Chapter 6 will detail the rationale and hypotheses that underlie the two central aims in this work. Chapters 7 and 8 will present the Methods, Results, and initial Discussions for Aims 1 and 2, and Chapter 9 will conclude with an integrated discussion of the findings.

2. MODELS OF READING AND READING IMPAIRMENT IN ADULTS

At present, understanding the considerable heterogeneity among reading disorders in bilingual adults is hampered by the lack of high-quality theoretical and empirical studies in bilingual alexia. Therefore, the alexia literature in monolinguals will be used to provide a starting point for examining aspects of bilingual alexia in later chapters. This chapter will begin by reviewing single word models of written language processing in healthy individuals to lay the foundation for understanding the various clinical profiles of alexia that have been identified in post-stroke individuals. This chapter will conclude with a brief survey of profiles of reading impairment—distinguishing between alexia writ large, and subtypes of *acquired dyslexia* in persons with aphasia based on overall patterns of impaired reading at the single word level. Overall, Chapter 2 provides a foundation for single word reading that is integral to: i) to understand the research questions and hypotheses for Aim 1 which are focused on elucidating potential differences in acquired dyslexia among BWA (and how they are different from MWA) and ii) build up our predictions about sentence level reading throughout Aim 2.

2.1. Psycholinguistic Models of Reading and Alexia

Over the last 50 years, two prominent models of reading impairment have been used to generate testable predictions in alexia research. The sections below will review the major hallmarks of both frameworks and discuss how each could account for bilingual reading behaviors in healthy and post-stroke individuals.

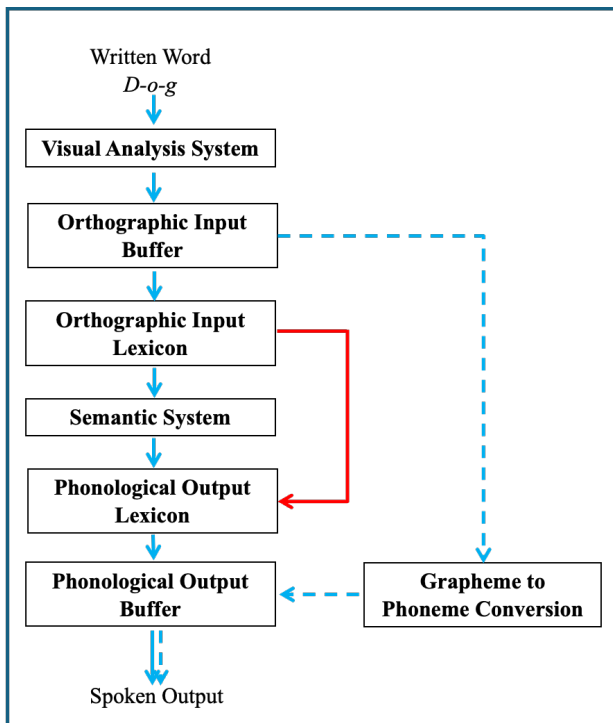
2.1.1. The Dual-Route Model of Reading

Although Coltheart (1980) is credited with first advancing a “dual-route model” that posited separate lexical and nonlexical pathways for oral reading and reading comprehension, evidence for this theoretical framework was first published in the early 1970s. Marshall & Newcombe (1973) proposed that oral reading was accomplished via semantics (i.e., meanings stored in memory) or via “putative grapheme-phoneme correspondence rules” (p.191). Forster & Chambers (1973) independently suggested that oral reading involved a cognitive race between two routes—one that involved a lexical search through memory for stored word pronunciations and one that mapped pronunciation directly from sound-letter correspondences. When confronted with a word, individuals would attempt to identify the word via both pathways simultaneously and the faster process would direct the final pronunciation. Instead of this “horse race analogy” (Coltheart, 2005), others argued that both routes contributed information during reading even if one of them proceeded faster and dominated the final spoken output.

In recent decades, a computational account of the dual-route model has been used to simulate the complex reading behavior encoded by separate lexical and nonlexical pathways. At its core, this dual-route cascaded (DRC; Coltheart et al., 1993; Coltheart et al., 2001) model is a sequential processing model that allows for reading i) regular words with predictable sound-letter correspondence, ii) irregular, or exception words, that do not have predictable sound-letter relationships and whose pronunciations must be learned, and iii) nonwords whose pronunciations must be computed via sound-letter(s) correspondence rules. A classical box-and-arrow version of the DRC model is shown in Figure 2.1 in which

the arrows between boxes broadly represent the capacity for excitatory and inhibitory connections between components. Therefore, the model is nonconnectionist in nature: it specifies interactions based on processes between components rather than strict connections between hypothesized, neuron-like units as is the case in other psycholinguistic models (Coltheart, 2005).

Figure 2.1 A Simplified Dual-Route Cascaded Model for Oral Reading



Caption. A box-and-arrow version of Coltheart et al. (2001)’s dual-route cascaded (DRC) model is shown where boxes represent cognitive components and arrows represent generalized excitatory and/or inhibitory links. The solid arrows represent a lexical route for reading whole words; words can be read by accessing their meaning (solid blue) or directly from memory, bypassing semantics (solid red). The dashed arrows represent a nonlexical route for reading words or nonwords via sound-grapheme correspondences.

The DRC model contends that oral reading begins when a word is presented to the Visual Analysis System which attends to feature units that are meaningful to letter

composition in a known orthography. Feature units in the Visual Analysis System project via excitatory inputs to letters that contain them and via inhibitory inputs to letters that do not contain them in the Orthographic Input Buffer for letter identification and string sequencing. If a letter string has an entry in the mental dictionary of the Orthographic Input Lexicon its meaning may be accessed via the Semantic System, or the pronunciation of the word may be directly retrieved from the Phonological Output Lexicon if its meaning is unknown (Schwartz et al., 1980). In either case, the word form and associated pronunciation that is activated will depend on similar waves of excitatory and inhibitory links between the Orthographic Input Lexicon, the Semantic System, and the Phonological Output Lexicon. Any letter string that does not have an entry in the Orthographic Input Lexicon will undergo decoding according to Grapheme-Phoneme Conversion (GPC) rules in an iterative, left-to-right fashion. Finally, the phonological sequence of the word will be composed and maintained in the Phonological Output Buffer before reading aloud.

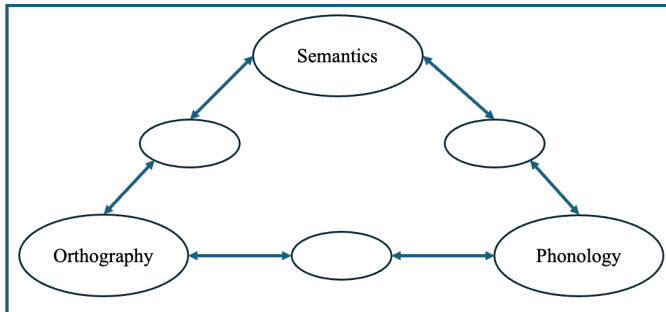
Using the DRC model, Coltheart et al. (2001) was able to replicate many reading behaviors observed in neurologically healthy and proficient readers. For example, they demonstrated that reading times (i.e., reaction times) were faster for real words vs. nonwords, high frequency words vs. low frequency words, regular words vs. irregular words, and high orthographic density words vs. low orthographic density words. At the level of the phonological output buffer, interactions between these lexicality, frequency, regularity, and neighborhood density effects—as they are respectively known—may arise due to the parallel activation of separate word-form pronunciations from the lexical and nonlexical routes (Coltheart et al., 2001). For example, in-tandem activation of the

nonlexical route during irregular word reading causes longer reading times for low frequency vs. high frequency irregular words (Paap & Noel, 1991; Seidenberg et al., 1984); likewise, activation of the lexical route during nonword reading leads to faster reading times for nonwords that have high orthographic neighborhood density (Coltheart, 2005; Coltheart et al., 2001).

2.1.2. The Triangle Model of Reading

In 1989, Seidenberg and McClelland proposed a separate theoretical framework for word reading that consisted of three interconnected systems: semantics, phonology, and orthography. Unlike the DRC model which has a sequential or serial processing architecture, this triangle model—named for interactions between these three systems—is a parallel-distributed processing (PDP) connectionist model. In the simplified version of this model shown in Figure 2.2., neuron-like units encode specific linguistic representations including conceptual features in the semantic system, phonetic features and phones in phonology, and visual features and letters in orthography. Communication between these nodes occurs in parallel via additional sets of neuron-like units distributed in hidden layer units that serve as interfaces for input-output processing between systems (Seidenberg, 2005).

Figure 2.2 A Simplified Triangle Model of Reading



Caption. A box-and-arrow version of Seidenberg & McClelland (1998)’s triangle model is shown where larger boxes represent principal language systems, smaller boxes represent interface units between them, and bidirectional arrows represent axon-like connections between neurons throughout the reading network.

Seidenberg and McClelland (1989) originally introduced the triangle model with two pathways, one direct from orthography to phonology and one indirect passing through semantics first (Coltheart, 2005), emphasizing its similarity to the classical dual-route model. Nevertheless, accurate word reading between the models is accomplished via different mechanisms. In the dual-route model, computation of a pronunciation from spelling is sequential and depends on rules such as phoneme-grapheme correspondences and lexicons. In the triangle model, however, there are no rules or mental dictionaries; instead, word reading depends on synchronized patterns of activation between the neurons in the principal systems and the layers between them based on principles of statistical learning. Entire cohorts of words and concepts are activated based on feed-forward and feed-backward loops to arrive at a singular pattern of activation that represents individual words. Certain units “settle into” patterns over time (Plaut et al., 1996) based on increasing reading experience and frequency weights develop between them; as a result, the final

activation sequence for a given word depends on the relative contributions of units in the entire reading network.

Initial testing of the triangle model simulated reading behaviors in a manner similar to the dual-route model. First, the model successfully replicated the frequency effect in reading, demonstrating that more common words were read faster than less common words. Additional work also showed that this frequency effect was modulated by neighborhood density; for example, effects were less robust for words like ‘gate’ that had many orthographic neighbors compared to words like ‘yacht’ which had few related words (Seidenberg, 2005). Repeated testing and tuning finally produced accurate reading for nonwords—a key aspect of the DRC model—based on robust phonological representations that developed early in model training (Harm & Seidenberg, 1999; 2004). Finally, unlike the DRC model, the triangle model could explain consistency effects (i.e., spelling-pronunciation relationships) in oral reading. For example, model simulations revealed that reading was more efficient for words like ‘must’ that had few irregular word neighbors compared to words like ‘gave’ which had several irregular neighbors (e.g., ‘have’).

2.1.3. Cross-linguistic Considerations

Despite their utility, models of reading have attracted criticism over the years because they were mostly developed to account for orthographic processing in English, potentially ignoring key aspects of other language writing systems. Indeed, contemporary theories such as the Orthographic Depth Hypothesis (ODH; Katz & Frost, 1992) contend that the orthographic structure of a given language may directly influence readers’ behaviors and strategies when comprehending or producing written language. For example,

Ardila (1991) and others have argued that readers of Spanish—a *transparent* (or *shallow*) orthography marked by almost one-to-one grapheme-phoneme correspondence—may not need a lexical strategy (or pathway) for reading because the highly regular nature of the orthography does not require word forms to be memorized. By contrast, readers of English—an *opaque* (or *deep*) orthography marked by many-to-many grapheme-phoneme correspondence—likely require a lexical strategy for reading exception words (e.g., *yacht*).

If these contentions prove true, then the dual-route model for reading would be a poor framework for transparent orthographies given its reliance on both a lexical and nonlexical (phonological) pathway. The triangle model, however, could more readily account for either type of orthography. In deep orthographies, the semantic-orthographic connections could contribute more to the activation patterns of irregular words during reading and in transparent orthographies, phonological connections throughout the system would likely be more dominant. Nevertheless, recent evidence and testing of the ODH suggests that lexical and nonlexical processes can be identified in readers of both orthographies (Besner & Smith, 1992). These data point to a *universality* of reading experiences in which readers of all languages develop both types of strategies although they may favor one based on orthography (Iribarren, 2007). We will return to this point frequently throughout the next section to argue that the same profiles of alexia, or acquired reading impairments, are possible in both English and Spanish. However, the linguistic behaviors that define each profile could differ between the two languages based on their orthographic differences—a point that has important implications for Aim 1.

2.2. Profiles of Acquired Dyslexia

Previous research has shown that damage to the reading networks illustrated in the DRC and triangle models may result in alexia or acquired reading impairment. Throughout this chapter and the remainder of this work, *alexia* will be used to refer to general reading impairments while *acquired dyslexia* will be used for describing specific constellations of reading deficits that represent a subtype diagnosis. Although numerous brain regions may be implicated in alexia, the clinical presentation of the acquired dyslexias varies considerably based on where the damage occurs. For example, the *peripheral dyslexias* arise due to deficits in visual processing prior to linguistic activation and are not usually considered language disorders since their associated pathology does not involve perisylvian regions, especially in the left hemisphere (Dehaene & Cohen, 2011; Epelbaum et al., 2008). Examples include *pure alexia* or *alexia without agraphia* (Patterson & Kay, 1982; Shallice & Saffran, 1986) after damage to the left hemisphere and *neglect* or *hemispatial dyslexia* following right hemisphere injury (Ellis et al., 1987; Hillis & Caramazza, 1990). In contrast to the peripheral dyslexias, the *central dyslexias* often co-occur with aphasia given that both are characterized by damage to perisylvian and other neural regions involved in language processing. Given that one of the overarching goals of this work is to relate aphasia and alexia, the presentation of the acquired dyslexias below will be limited to the central dyslexias.

It is important to note that the DRC and triangle models generate different predictions about the relationship between alexia and aphasia following left hemisphere injury. In the DRC model, for example, injury to the Semantic System—a component

necessary for several types of language processing—is expected to produce symptoms of both aphasia and alexia whereas damage to the Orthographic Input Lexicon—necessary only for word reading—may only drive alexia symptoms. By contrast, the triangle model holds that damage to any central system or the connections between them is likely to result in generalized language difficulties inherent in aphasia and alexia. This primary systems hypothesis (PSH)—that the central components in the triangle model are modality-independent for language processing (Lambon Ralph & Patterson, 2007; Patterson & Lambon Ralph, 1999)—views reading and writing as evolutionary and “parasitic” (Woollams, 2014) developments of the existing cognitive infrastructure for semantic, phonological, and generalized visual processing (the PSH stipulates orthography is one function of a central visual processing component). Given that reading is always acquired later in life regardless of individual language learning, the PSH expects robust relationships between spoken language and written language deficits.

Several subtypes of central dyslexia have been described in the literature (see Cherney, 2004 for a review) based on neuroanatomical findings and clinical profiles of reading behavior. This section will introduce the four most common profiles: surface, direct, phonological, and deep dyslexia, reviewing evidence for English and Spanish where necessary while considering the available neuroanatomical and behavioral evidence for differences in clinical presentation. As discussed in section 2.1.3, similar profiles of acquired dyslexia are expected for English and Spanish (Iribarren, 2007); however, the same profile may be diagnosed according to a different set of behavioral markers in both languages as we will see in the forthcoming sections. Table 2.1 at the end of the section

provides a summary of the dyslexias and associated symptoms for both languages.

2.2.1. Surface Dyslexia

Surface dyslexia occurs due to damage to inferolateral left temporal regions implicated in semantic processing (Vandenberghe et al., 1996). In the DRC model, surface dyslexia is localized to a problem with the lexical reading route involving the Orthographic Input Lexicon, the Semantic System, or the connections between them. In the triangle model, surface dyslexia is characterized by central semantic impairment or reduced activation in the Semantics-Phonology (S-P) layer (Patterson & Lambon Ralph, 1999). Individuals with surface dyslexia typically present with a difficulty in reading whole words accurately because access to lexical representations has been disrupted; as a result, readers revert to phonological-based reading strategies that may work for reading nonwords or highly regular words but are insufficient for exception/irregular words (see Coltheart et al., 1983 for a review).

In opaque orthographies such as English which contain large amounts of irregular words, the major hallmark of surface dyslexia is a regularity effect: oral reading and reading comprehension of irregularly spelled words is much poorer than regularly spelled words. Oral reading errors tend to be visual errors (Cherney, 2004) in which a word is read aloud as another word with a similar word form (e.g., 'bore' for *bone*) or regularization errors (Patterson & Behrmann, 1997) in which a word is read incorrectly, using grapheme-phoneme correspondence rules in the language (e.g., [jaʃt] for *yacht*). In transparent orthographies such as Spanish, there are few irregularly spelled words and surface dyslexia must be diagnosed in other ways. For example, Spanish readers with surface dyslexia may

show impaired lexical stress production—a specific type of regularization error—such as reading *corazón* [ko ra ‘son] as **corázon* [‘ko ra son] or they may show longer reaction times and less accurate judgements of pseudohomophones (Ferrerres et al., 2005; Ferreres et al., 2012) during lexical decision tasks. Another study by Iribarren et al. (1996) reported a Spanish reader who had trouble identifying written homophone words (e.g., *ola*, ‘wave’ and *hola*, ‘hello’) that appeared in a sentence read aloud to him. Both these homophone confusions and the pseudohomophone confusions above may be classified as types of visual errors that arise due to the destabilization of whole word representations in the reading network.

2.2.2. Direct Dyslexia

In contrast to surface dyslexia, direct dyslexia, also known as semantic dyslexia (Cherney, 2004), may have a more widespread neuroanatomical profile. Typically, direct dyslexia involves at least some focal or functional damage to the left anterior temporal lobe given that is frequently observed in conjunction with semantic dementia (Ripamonti et al., 2014). Individuals with direct dyslexia can read words—even irregular ones—aloud but cannot comprehend their meaning due to inconsistent access to semantic representations (Schwartz et al., 1980). This behavior has led some researchers to posit that a lexical, non-semantic route exists in the DRC model (Coslett, 1991) directly linking the Orthographic Input Lexicon and the Phonological Output Lexicon (see the red arrows in Figure 2.1) that may be used when there is damage to the Semantic System. Under this framework, more activation from the nonlexical route may support the damaged lexical route, leading to phonologically plausible errors during oral reading of irregular words (e.g., ‘soot’ for suit).

Based on the degree of Semantic System damage, others like Shallice et al. (1983) have suggested a noisy interplay between residual semantic activation and phonological activation from grapheme-phoneme conversion procedures may explain clinical symptoms of the disorder. Hillis and Caramazza (1991) have also reported that—in addition to the phonological errors in oral reading—individuals with direct dyslexia may demonstrate semantic errors in naming and single word auditory comprehension and poor performance on reading comprehension tasks such as word-picture matching.

Although cases of direct dyslexia have not been reported among Spanish readers thus far, a similar set of behavioral markers identified in English readers are likely to characterize the disorder in Spanish as well. Given that direct dyslexia arises from damage to the semantic system but with preserved oral reading, Spanish readers should display little difficulty in reading words aloud based on the transparent nature of grapheme-phoneme correspondences. Phonologically plausible errors would still be possible but would likely be reduced compared to English readers given the relative strength of phonological representations in Spanish. Most importantly, Spanish readers would be expected to perform similarly on other language measures, demonstrating semantic errors across naming, written word-picture matching, and single word auditory comprehension tasks.

2.2.3. Phonological Dyslexia

Lesions resulting in phonological dyslexia (Beauvois & Dérouesné & Beauvois, 1979; Dérouesné & Beauvois, 1979) have been traced to various perisylvian cortical regions (Rapcsak et al., 2009) including frontal, temporal, and parietal areas (Dérouesné &

Beauvois, 1979; Friedman, 1996; Marchand & Friedman, 2005) that form part of the distributed network for phonological processing (Ripamonti et al., 2014). The hallmark feature of phonological dyslexia is a lexicality effect characterized by poor performance on reading nonwords but intact reading of real words, especially high frequency words. Nonwords are typically lexicalized—meaning they are assigned a pronunciation consistent with a phonologically or orthographically-related word (e.g., *fabe* read as ‘fate’ or ‘babe’; Patterson & Lambon Ralph, 1999). Additionally, imageability (Crisp & Lambon Ralph, 2006), part-of-speech (Friedman, 1996; Glosser & Friedman, 1996), and grammaticality effects (Funnell, 1983; Glosser & Friedman, 1990) have also been observed as captured by better accuracy for concrete nouns vs. abstract nouns, verbs, and functor words (i.e., prepositions, pronouns, etc.), respectively. In the DRC model, these lexical effects and the nonword reading impairment arise from focal damage to the grapheme-phoneme conversion rules that define the nonlexical route. In the triangle model, phonological dyslexia is attributed either to a frank phonological deficit or reduced levels of interaction between the Phonology-Semantics (P-S) nodes (Patterson & Lambon Ralph, 1999). Without appropriate phonological activation, pronunciations for words with underspecified or less densely associated semantic representations such as abstract nouns or functors become more prone to error (Crisp & Lambon Ralph, 2006).

Spanish readers with phonological dyslexia also present with a characteristic lexicality effect in oral reading—better accuracy on real words vs. nonwords (Iribarren, 2007). Nevertheless, several studies examining single cases of phonological dyslexia in Spanish have presented conflicting descriptions of secondary symptoms, several of which

do not mirror the clinical evidence in English. For example, one Spanish monolingual with phonological dyslexia from Cuetos et al. (1996) did not demonstrate grammaticality or imageability effects in oral reading and their errors consisted of mostly phonological errors during nonword reading (i.e., they produced nonword-nonword substitutions). By contrast, Iribarren et al. (1999) also presented cases of phonological dyslexia in two Spanish monolinguals that were characterized by word category effects in oral reading like the English results above; the individuals also read short words better than long words, but imageability had no effect on their accuracy and they produced mostly morphological/derivational errors during oral reading such as *peresozo* ‘lazy’ for *pereza* ‘laziness’. Given the small samples reported in the literature, it is difficult to entirely rule out secondary symptoms in Spanish that are observed in English such as imageability and grammatical class effects. Indeed, with larger samples and more uniform clinical testing, it should be possible to more clearly define the clinical characteristics of phonological dyslexia in Spanish.

2.2.4. Deep Dyslexia

Often described as the most severe profile, deep dyslexia commonly results from widespread lesions to fronto-temporo-parietal perisylvian regions (Klein et al., 1994; Marshall & Newcombe, 1973; Price et al., 2003; Warrington & Shallice, 1973). Individuals with deep dyslexia have difficulty reading real words and nonwords consistent with both semantic and phonological impairment, respectively. During oral reading of real words, individuals may produce semantic paralexias—the hallmark deficit of the disorder. Semantic paralexias may be category coordinates (e.g., dog-cat), superordinates (e.g., dog-

animal), antonyms (e.g., hot-cold), synonyms (e.g., save-rescue), or other associated responses. Oral reading may also be characterized by visual and morphological/derivational (e.g., editor-edition) paralexias (Crisp & Lambon Ralph, 2006) as well as imageability and part-of-speech effects—behaviors typically associated with phonological alexia. In fact, many scholars have suggested that deep dyslexia is just a severe form of phonological dyslexia rather than a separate acquired reading disorder (Crisp & Lambon Ralph, 2006; Friedman, 1996; Glosser & Friedman, 1990).

Strong support for this theory was provided by Friedman (1996) who observed combinations of imageability, part-of-speech, grammaticality (i.e., functor), and lexicality effects in 11 patients diagnosed with deep dyslexia. After reading intervention, the patients demonstrated a reliable pattern of recovery: none showed semantic paralexias, some showed imageability, grammaticality, and part-of-speech effects, but all continued to show lexicality effects (i.e., impaired nonword reading). From these findings, Friedman (1996) proposed the phonological-deep continuum of dyslexia in which deep dyslexia could be interpreted as phonological dyslexia plus semantic impairment leading to semantic paralexias. The triangle model attributes deep dyslexia to frank impairments in the central semantics and phonological components and/or even further reduced activation between the P-S units between them (consistent with more severe phonological alexia). In the DRC model, deep dyslexia is hypothesized to arise from damage to both the lexical and nonlexical reading routes. More specifically, there must be damage to the Semantic System to account for the semantic paralexias.

Deep dyslexia in Spanish is mostly consistent with the patterns presented for English. Across several case studies, Spanish monolingual readers all showed impaired nonword reading and semantic paralexias on measures of oral reading, pointing to the diagnostic utility of these features in Spanish (Ardila, 1998; Davies & Cuetos, 2005; Plasencia et al., 2008; Ruiz et al., 1994). Accuracy for real words was more variable across the participants but all demonstrated derivational and/or visual errors on these stimuli. Ruiz et al. (1994) also reported grammaticality and part-of-speech effects akin to those observed in both phonological and deep dyslexia in English readers. Additionally, the participant in Plasencia et al. (2008) produced lexicalization errors during nonword reading. These secondary patterns may provide emerging evidence for a phonological-deep continuum in Spanish as well as English.

2.3. Summary

In sum, both the DRC and triangle models provide useful frameworks for describing reading behaviors in healthy individuals and patterns acquired dyslexia in PWA. Across patterns of dyslexia, similar symptoms have been observed in both Spanish and English readers that point more to a *universality* of reading experiences—even after stroke—than to separate cognitive-linguistic experiences. Regardless, it is important to mention that the contemporary evidence for dyslexia profiles in Spanish is mostly limited to single cases in monolingual readers. It remains unknown whether bilingual Spanish-English readers would show similar patterns in both languages and whether the same symptoms would be observed across languages. These open questions will be returned to in later sections of this work to motivate the hypotheses and analyses in Aim 1.

Table 2.1 Lesion Characteristics, Psycholinguistic Descriptions, and Symptoms of the Major Central Dyslexia Subtypes in English and Spanish

Type	Lesion Characteristics	DRC Breakdown	Triangle Breakdown	English Symptoms	Spanish Symptoms
Surface	Inferolateral left temporal regions	Lexical Route: • Orthographic Input Lexicon • Semantic System	• Central Semantic • Reduced S-P activation	<ul style="list-style-type: none"> • Regularity Effect (i.e., regular words > exception words) • Visual Errors • Regularization Errors (e.g., [jaʃt] for <i>yacht</i>) 	<ul style="list-style-type: none"> • Impaired lexical stress/Regularization Errors • Pseudohomophone confusions • Homophone confusions in lexical decision
Direct	<ul style="list-style-type: none"> • Structural- Damage to left anterior temporal lobe (IATL) • Functional- Disconnection between IATL and frontal lobe or occipital lobe via uncinate or inferior longitudinal fasciculi 	Lexical Route: Semantic System	• Central Semantic • Reduced S-P activation	<ul style="list-style-type: none"> • Poor comprehension of word meaning although intact word reading • Semantic Errors in picture naming • Poor single word auditory comprehension • Phonological Errors (e.g., ‘soot’ for <i>suit</i>) 	Expected to be the same as English w/ reduced number of phonological errors
Phonological	Fronto-temporo-parietal perisylvian regions that form phonological processing network	Nonlexical Route: Grapheme-Phoneme Correspondence Rules	• Central Phonological • Reduced P-S activation	<ul style="list-style-type: none"> • Lexicality Effect (i.e., real words > nonwords) • Imageability Effect (i.e., concrete > abstract) • Part-of-speech Effect (i.e., nouns > adjectives > verbs) • Grammaticality Effect (i.e., content words > functors) • Lexicalization Errors (e.g., ‘fate’ or ‘babe’ for <i>fabe</i>) 	<ul style="list-style-type: none"> • Lexicality Effect (i.e., real words > nonwords) • Part-of-speech Effect (i.e., nouns > adjectives > verbs) • Derivational Errors (e.g., ‘peresozo’ for <i>pereza</i>) • Lexicalization Errors (e.g., ‘maji’ [taxi] for <i>bami</i>)
Deep	Severe damage to fronto-temporo-parietal perisylvian regions	<ul style="list-style-type: none"> • Lexical Route AND • Nonlexical Route 	<ul style="list-style-type: none"> • Central Phonological • Central Semantic • Reduced S-P/P-S activation 	<ul style="list-style-type: none"> • Semantic Paralexias (e.g., ‘hot’ for <i>cold</i>; ‘nurse’ for <i>hospital</i>) • Impaired real word and nonword oral reading • Derivational Errors (e.g., ‘editor’ for <i>edition</i>) • Imageability Effect • Part-of-Speech Effect • Grammaticality Effect 	<ul style="list-style-type: none"> • Semantic Paralexias (e.g., ‘terrazza’ [terrace] for <i>balcón</i> [balcony]) • Impaired real word and nonword oral reading • Derivational Errors • Part-of-Speech Effect • Grammaticality Effect

Note. Unless otherwise specified, errors and effects refer to oral reading behaviors. *Lesion Characteristics* reports the common neurological pathology associated with each type of acquired dyslexia. *DRC Breakdown* indicates which routes are implicated in the Dual-Route Cascaded Model for each dyslexia. *Triangle Breakdown* conveys the potential sites of damage from the Triangle Model. *English Symptoms* denote characteristics of each subtype observed in English readers while *Spanish Symptoms* denote the same for Spanish readers. Primary symptoms in each language are listed in red, bold type. Symptoms in each language were included if they were observed in the clinical literature.

3. PROFILES OF ALEXIA IN INDIVIDUALS WITH APHASIA

The models of reading discussed in the previous chapter provide a robust framework for understanding written language processing in healthy individuals and how damage to these networks can lead to alexia and acquired dyslexia. Building on this foundation, the present chapter explores profiles of dyslexia in individuals with aphasia—highlighting differential patterns in clinical presentation and diagnosis. This detailed examination is critical for understanding the variability in impairment across monolingual and bilingual individuals, as well as for elucidating the patterns of impairment that form the basis of Aim 1.

3.1. Profiles of Alexia and Acquired Dyslexia in MWA

In this section, several aspects of reading impairment are explored to characterize the clinical presentation of alexia in MWA. Specifically, the frequency and severity of profiles of acquired dyslexia, severity and type of reading comprehension difficulty, and relative co-occurrence of other linguistic deficits alongside reading impairment are examined. Investigating these aspects of impairment should enable identification of commonalities between MWA and justify individual variability in alexia presentation. These patterns also provide a strong foundation for comparison with patterns among BWA presented in the second half of this chapter.

3.1.1. Frequency and Severity of Acquired Dyslexia

In recent years, a few large cohort studies have enabled researchers to examine the relative frequency and severity of acquired dyslexia profiles among PWA. For example,

Beeson et al. (2022) examined acquired dyslexia subtypes by investigating differences in performance on a series of oral reading tasks between 87 PWA and 38 neurotypical controls. For each participant, they computed the difference in percent accuracy for real words vs. nonwords and regular words vs. irregular words to calculate individual lexicality and regularity indices, respectively. Then, they compared the indices for each PWA to the distribution of the indices for all neurotypical controls using a single subject test. The distribution of profiles based on the data were: 59% phonological dyslexia, 34% global dyslexia, or near total impairment in oral reading, 5% unclassifiable (i.e., no lexicality or regularity effects), and 2% unimpaired. There were no PWA diagnosed with surface or direct dyslexia which suggests that although several subtypes of acquired dyslexia have been identified (as introduced in Chapter 2), subtypes like surface and direct dyslexia may be rarer diagnoses.

By contrast, Brookshire et al. (2014) and Madden et al. (2018) assessed acquired dyslexia across 43 PWA using a single subject design in which each PWA served as their own standard for comparing accuracy and error patterns across word types. The authors of both studies constructed 95% confidence intervals for oral reading scores across regular words, irregular words, pseudohomophones, and nonwords and determined diagnoses by directly comparing the confidence intervals. For example, PWA were diagnosed with surface dyslexia if they produced regularization errors and showed independent (i.e., nonoverlapping) confidence intervals for regular words vs. irregular words and nonwords vs. irregular words, reflecting significantly lower scores for oral reading of irregular words (i.e., a regularity effect). Phonological dyslexia was suggested when PWA produced

lexicalization errors and showed independent confidence intervals for all real words vs. nonwords, revealing lower scores for oral reading of nonwords (i.e., a lexicality effect). Deep dyslexia was marked by the presence of semantic paralexias, a lexicality effect consistent with the study's definition of phonological alexia, and at most, 50% accuracy on all oral reading tasks. Finally, global dyslexia was proposed for any PWA scoring 10% correct or less across all oral reading tasks. Based on these data, the distribution of profiles of dyslexia was: 53% phonological dyslexia, 9% deep dyslexia, 12% global dyslexia, 12% unclassifiable, and 14% unimpaired. Additionally, none of the PWA presented with signs of surface dyslexia. Overall, these proportions were in line with the findings from Beeson et al. (2022), pointing to phonological dyslexia as the most common clinical syndrome and surface dyslexia as the rarest.

3.1.2. Reading Comprehension and Profiles of Alexia

The patterns in the studies above were uncovered based on abnormal performance on a variety of oral reading tasks to diagnosis acquired dyslexia; nevertheless, PWA who are diagnosed with alexia also often struggle with silent reading. Since comprehension requires linking meaning with orthography, deficits may be evident when reading a combination of single words, sentences, paragraphs, and texts. For example, Meteyard et al. (2015) found variable profiles of difficulty in reading comprehension after analyzing word, sentence, and text-based comprehension for four PWA. Their results showed that most participants had intact single word comprehension and intact sentence or text comprehension but not both. The authors suggested that text comprehension could be easier for some PWA if more semantic-syntactic context could support sentence-level difficulties;

alternatively, sentence comprehension could appear easier if the participants became exhausted by length effects in reading texts.

Webb and Love (1983)—who also examined single-word, sentence, and paragraph comprehension skills in 35 PWA—found their participants had trouble with reading at all levels although they struggled with sentence comprehension the most. Additionally, the authors reported that general reading ability was associated with silent reading comprehension among their cohort. More specifically, they uncovered a strong relationship between performance on reading comprehension tasks and an aphasia severity measure (i.e., more severe reading comprehension difficulties were associated with more severe aphasia). These results are consistent with findings from Webster et al. (2022) that showed strong positive correlations between reading comprehension performance across single words, sentences, and texts based on data from 43 PWA.

3.1.3. Other Linguistic Deficits and Alexia

Although the previous sections focused on patterns in acquired subtypes of dyslexia and deficits in reading comprehension, our discussion of alexia in MWA would be incomplete without examining concomitant deficits in spoken language which also emerge following damage to language processing networks post-stroke. Indeed, the seeming independence of spoken and written language processes have been challenged recently by work aligned with the PSH and triangle model that suggests damage to the interconnected systems of orthography, phonology, and semantics may be enough to account for patterns of impairment across language tasks. For example, Crisp and Lambon Ralph (2006) administered a variety of spoken and written phonological and semantic tasks to 11

individuals with suspected left hemisphere lesions to identify potential relationships between modalities. At the group level, individuals demonstrated a lexicality effect in both spoken word repetition and oral reading. More importantly, this single lexicality effect was modulated by conceptual knowledge such that participants with greater semantic impairment had smaller lexicality effects (i.e., semantic damage decreased correct reading of real words and reduced the lexical effect). Overall, the authors concluded that only a common locus of phonological impairment—rather than separate loci of damage for spoken and written phonological processing deficits—could explain the pattern of results across word repetition and oral reading.

Madden et al. (2018) also investigated potential relationships between written and spoken language skills by examining how non-orthographic phonological and semantic abilities could influence orthographic processing. More specifically, the authors used: i) a composite measure of phonology based on performance across tasks such as minimal pair judgment, rhyme judgement, and sound isolation/blending and ii) a composite measure of semantics based on performance across tasks such as spoken word picture-matching, auditory synonym judgment, and picture association to predict performance on oral reading and reading comprehension subtests. The oral reading results revealed that although semantics and phonology both predicted total reading scores, the semantics composite also predicted accuracy across word types (i.e., regular words, irregular words, pseudohomophones, and nonwords) whereas the phonology composite only predicted accuracy for pseudohomophones and nonwords. In reading comprehension, greater semantic performance predicted better comprehension across levels of complexity whereas

greater phonological performance only predicted sentence-level comprehension. The authors surmised that phonology predicted sentence-level performance and not single-word performance for two reasons. First, some of the phonological composite tasks like rhyme judgment and sound blending could have indexed phonological working memory; greater scores on the composite, then, would have signaled participants who were more able to handle the working memory demands placed on them during sentence comprehension. Second, single words may be activated and comprehended without accessing each phoneme in the word, so phonology could have emerged as a less important predictor if several PWA were accomplishing word recognition in this manner.

Like Crisp and Lambon Ralph (2006), Rapcsak et al. (2009) also reported lexicality effects in a sample of 31 PWA—this time in spelling tasks in addition to reading and spoken repetition tasks. Results showed that participants performed poorly on a phonological battery that did not include orthographic processing tasks, lending support to the idea that a modality-independent, central phonological deficit could explain various phonological processing difficulties post brain injury. Despite this support for a shared systems model of language processing, the authors noted that the severity of the phonological deficit did vary across the tasks. For example, participants performed significantly worse on spelling tasks compared to reading tasks, suggesting that even in a shared systems framework, language abilities could be differentially impaired.

Years later, Beeson et al. (2022) performed a follow-up study in which they examined spoken and written language processing skills in 87 PWA (including the 31 participants from Rapcsak et al., 2009) and 38 neurotypical controls to better understand

connections between aphasia, alexia, and agraphia. Using principal components analysis, their results showed that performance across spoken and written language tasks could be explained by a five-factor solution loading onto three central components including semantics, phonology, orthography and two peripheral components including speech production (i.e., to capture variation in motor speech), and allographic skill (i.e., to capture variation in handwriting). Crucially, despite differences in aphasia type and severity, PWA showed “unifying” features of phonological deficits across aphasia, alexia, and agraphia, further underscoring the predictive strength of the PSH and triangle model.

3.1.4. Summary

Overall, findings across studies in *3.1.1* highlight the considerable variability in alexia severity among MWA, ranging from no impairment to the most severe form of reading difficulty, global dyslexia. Among individuals diagnosed with acquired dyslexia, phonological dyslexia emerged as the most common profile in studies that relied on oral reading performance measures—such as overall accuracy, word-category accuracy, and oral reading errors—to classify impairment (Beeson et al., 2022; Madden et al., 2018). In contrast, semantically mediated profiles, such as surface dyslexia, appear to be significantly rarer in MWA. Several factors may help explain these trends. One possibility is that access to phonological representations is particularly vulnerable to disruption following stroke, making phonological dyslexia the most prevalent outcome. Alternatively, but not contradicting this view, the phonological network may be so widely distributed across neural substrates that it is especially susceptible to damage, regardless of lesion size or location. This widespread distribution could explain why phonological impairments are

frequently observed across diverse cohorts of individuals with stroke-induced aphasia.

In section 3.1.2, reading comprehension deficits varied across studies due to individual differences among MWA; nevertheless, overall patterns revealed strong positive associations between reading comprehension for single words, sentences, and texts. That is, individuals who performed better at one level of reading comprehension tended to show stronger performance across other levels as well. Beyond these associations, different linguistic skills appeared to contribute uniquely to reading comprehension. Across all levels of complexity, stronger performance on non-orthographic semantic processing tasks was associated with better reading comprehension. By contrast, non-orthographic phonological processing abilities were only predictive of sentence-level comprehension and this dissociation may highlight distinct contributions of phonological and semantic processing to reading comprehension outcomes. Finally, studies in this section also pointed to a strong relationship between overall aphasia severity and reading comprehension: individuals with milder aphasia exhibited less severe reading comprehension deficits, reinforcing the links between spoken language impairment and reading comprehension deficits among MWA as proposed by the Triangle Model and PSH.

Finally, several studies in section 3.1.3 identified strong parallels between spoken and written language impairments, suggesting a shared phonological processing deficit rather than distinct loci of impairment for spoken and written language. For example, Crisp and Lambon Ralph (2006) and Rapcsak et al. (2009) observed similar lexicality effects across oral word repetition, oral word reading, and oral spelling which they argued arose from a central phonological impairment affecting all three modalities. This evidence for a

core phonological processing deficit helps explain variation in phonological abilities following brain injury and may contribute to the frequency and severity of acquired dyslexia subtypes. In particular, the prevalence of phonological dyslexia across large cohort studies in section 3.1.1 aligns with the idea that phonological processing disruptions are a primary driver of written language impairment in MWA. Additionally, as discussed in the previous section, non-orthographic semantic processing was a significant predictor of reading comprehension across different levels of complexity. These findings suggest that both phonology and semantics (as measured by non-orthographic processing tasks) play a role in shaping reading ability post-brain injury, underscoring the importance of assessing both linguistic domains when characterizing acquired dyslexia in PWA.

3.2. Profiles of Alexia and Acquired Dyslexia in BWA

In contrast to monolingual adults, the clinical phenotype of alexia and acquired dyslexia in BWA is shaped by differences in individuals' premorbid language and literacy backgrounds, postmorbid language impairment, and the characteristics of their acquired brain injuries. However, understanding this considerable heterogeneity remains challenging due to the limited number of high-quality theoretical and empirical studies on bilingual aphasia and alexia. As a result, several key clinical questions remain unanswered such as: (1) To what extent do bilingual individuals exhibit differences in the severity of alexia and frequency of acquired dyslexia across their two languages? (2) What is the relationship between spoken language impairment (aphasia) and reading impairment (alexia) in bilingual individuals? (3) How do orthographic differences between languages influence impairment profiles in bilingual individuals? This section reviews existing

studies in bilingual alexia to explore evidence that addresses these questions, highlights remaining gaps in the literature, and provides contrasts to the monolingual aphasia research discussed earlier in the chapter. Before turning to specific studies, however, it is first necessary to consider the broader patterns of impairment observed in bilingual aphasia. Given that bilingual individuals must manage two language systems, the extent and nature of alexia may not be uniform across their languages. Just as spoken language impairment in bilingual aphasia has been classified into distinct patterns of relative impairment across languages, these classifications—parallel, differential, and selective impairment—may also provide a useful framework for understanding reading deficits in BWA.

3.2.1. General Impairment Profiles

Despite the large degree of linguistic variability inherent among bilinguals, several profiles of impairment have been identified in the literature that suggest underlying patterns in post-stroke deficits (Paradis, 2004). The main profiles that may characterize bilingual abilities after brain injury are parallel, differential, and selective impairment. To diagnose an individual according to one of these profiles, clinicians must evaluate post-stroke language abilities—as determined by performance across clinical testing—in the context of pre-stroke language proficiency. That is, care must be taken to ensure that poor performance on language testing reflects a decline in an individual's pre-stroke, or baseline abilities. In this case, parallel impairment is defined as comparable damage in each language that appears commensurate with a decrease in pre-stroke language abilities. This may occur regardless of severity and independent of differences in pre-stroke language abilities between languages. In differential impairment, both languages become damaged,

but one is more severely affected than the other after accounting for pre-stroke abilities. Finally, in selective impairment, deficits may be present in one language and absent in the other relative to a pre-stroke baseline.

Several studies have reported conflicting findings regarding which impairment profile is most common among BWA. For example, parallel impairment was the predominant pattern in 88% of the 25 participants described by Peñaloza et al. (2020), 65% of the 20 participants in Fabbro (2001), and 61% of the 132 individuals in Paradis (2001). By contrast, a recent systematic review and meta-analysis by Kuzmina et al. (2019) found that differential impairment was the most frequent pattern among 119 bilinguals with aphasia. Crucially, both Peñaloza et al. (2020) and Kuzmina et al. (2019) acknowledged that factors such as age of second language acquisition, language use, and premorbid proficiency influence impairment patterns, highlighting the role of individual linguistic backgrounds. Both studies also reported that, across most BWA, L1 abilities remained more intact post-stroke than L2 abilities, and individuals with stronger premorbid L1 proficiency tended to retain higher post-stroke L1 abilities. These patterns—despite discrepancies in reported prevalence rates—underscore the importance of considering pre-stroke language proficiency when predicting post-stroke spoken language outcomes.

However, a critical gap in the literature remains: no large-scale studies of bilingual aphasia have examined how these impairment profiles manifest in reading. Because parallel, differential, and selective impairment are the only possible ways bilingual language deficits can present, it is a given that these profiles must manifest in reading impairment as well. What remains unknown, however, is the *distribution of these profiles*

in reading impairment, whether they always align with spoken language profiles, and how they interact with different acquired dyslexia subtypes. For example, it could be that reading impairment among BWA is consistently parallel, meaning that both languages exhibit equivalent reading deficits regardless of how spoken language is affected. Alternatively, reading impairment may show greater variability, such that a person could exhibit parallel impairment in spoken language but differential impairment in reading. Furthermore, the interaction between impairment profiles and acquired dyslexia subtypes remains unexplored. If a bilingual individual presents with different types of acquired dyslexia across their two languages, does this reflect an underlying differential impairment pattern, or can an individual with parallel reading impairment still demonstrate distinct subtypes in each language perhaps due to differences in orthographic depth or phonological processing demands? These open questions highlight the need to investigate the frequency, severity, and interaction of impairment profiles with acquired dyslexia subtypes in bilingual alexia. The next section will examine available evidence to address these issues and while providing additional background for Aim 1.

3.2.2. Reading-specific Impairment Profiles

The current evidence base for alexia in BWA is mostly composed of single-case studies that examine potential differences in oral reading and/or reading comprehension abilities post-injury. Several of these studies have also focused on analyzing languages with different scripts (e.g., Japanese and English) to determine whether extreme differences in orthographic structure influence the development of cognitive-linguistic networks for reading. Although these details are not central to this work, several of these studies will be

reviewed in this section for their findings about general patterns of bilingual alexia. Cross-sectionally (i.e., within BWA), it is crucial to determine whether an individual shows comparable patterns of deficits and/or profiles of acquired dyslexia while reading in their two languages. Furthermore, it is important to examine whether larger-scale patterns can be discerned such as whether individuals experience greater reading severity in one language or the other. Examining these principles will help identify current gaps in clinical knowledge and lay the final foundation for Aim 1.

The most consistent finding in the clinical literature on alexia is that BWA (see Table 3.1 for a summary of studies) present with cross-linguistic dissociations in their reading abilities after a brain injury (Goral, 2019). More specifically, many studies report BWA with patterns of differential impairment in which reading abilities in one language have *decreased more* than another after accounting for pre-morbid proficiency. For example, Lyman et al. (1983) presented a case of a Chinese-English BWA who had more severe reading impairment in his L1-Chinese compared to his L2-English despite reporting equally strong reading abilities pre-injury. During oral reading testing, the case participant demonstrated letter-by-letter strategies to support his reading in English but did not employ strategies in Chinese (the same letter-by-letter reading strategy is unavailable in Chinese). It is difficult to draw further conclusions about reading performance because the authors did not report acquired subtype diagnoses in either language.

Both Ibrahim (2009) and Weekes et al. (2007) also reported differential impairment—in the absence of dyslexia subtypes—for one and eight BWA, respectively, although their participants demonstrated greater impairment in their L2. In Ibrahim (2009),

an Arabic-L1 and Hebrew-L2 BWA showed reading impairment in both languages that was more severe in Hebrew. After generalized language therapy, the participant demonstrated selective recovery for reading in which only Arabic improved and Hebrew did not. Like the participant in Lyman et al. (1983), this Arabic-Hebrew participant also employed a letter-by-letter reading strategy in Arabic but did not attempt any strategies in Hebrew (letter-by-letter reading is also not possible in Hebrew). The participants in Weekes et al. (2007) were Mongolian-L1 and Chinese-L2 BWA in which 3/8 showed greater oral reading impairment in L2-Chinese. Four participants showed no overt impairment in either language while one exhibited slightly less impairment in Mongolian. Although Mongolian and Chinese differ in script, the authors emphasized that script differences did not account for the observed reading impairment patterns in the half of the participants that showed a decline in reading ability. Instead, they attributed the results to language background factors, particularly proficiency and familiarity with reading in each language. This suggests that individual differences in language exposure and literacy experience, rather than orthographic structure, may play a key role in determining the severity and profile of reading impairment.

Other studies have also demonstrated differential impairment in combination with reported dyslexia subtypes. Ohno et al. (2002) tested the oral reading and reading comprehension abilities of a Japanese-L1 and English-L2 BWA in which formal assessment revealed pure dyslexia that was more severe in Japanese. Furthermore, between the two writing systems available in Japanese, the participant had more trouble reading kana (phonologically-based script) relative to kanji (logographic script). The participant

learned English later in life and the authors suggested this could partially explain the differential pattern of better spared reading in L2. In a similar case report, Raman and Weekes (2005) presented a Turkish-L1 and English-L2 BWA who showed acquired surface dyslexia in both languages. Given that Turkish is a transparent language and English is opaque, the authors expected more lexical reading difficulties in English. However, results showed impaired lexical reading in both languages that was captured by damaged phonological representations although impairment was greater in L2 than L1. Finally, Karanth (2002) also reported a case of differential impairment in a Hindi-L1 and English-L2 multilingual individual with aphasia. The participant was diagnosed with deep dyslexia in English—characterized by semantic paralexias, poor nonword reading, and an imageability effect—compared to a profile of pure dyslexia in Hindi. The author’s description for the near total cessation of reading in Hindi, however, suggests that global dyslexia may have more appropriate. Regardless, the study suggests that an overall profile of differential impairment may occur in concert with different diagnoses of acquired dyslexia across languages.

On the other hand, some studies have reported parallel impairment in reading. Senaha and Parente (2012) presented the case of a Japanese-L1 and Portuguese-L2 BWA who showed impaired lexical reading in both Japanese kanji and the transparent Portuguese script. The participant was subsequently diagnosed with surface dyslexia that was of comparable severity across both languages. In another study, Béland and Mimouni (2001) reported a case of deep dyslexia in an Arabic-L1 and French-L2 BWA. In both languages, deep dyslexia was marked by lexicality, function word, and imageability effects although

there were additional characteristics that were language specific. In French, the participant produced more semantic paralexias and in Arabic the participant showed a grammatical class effect (i.e., nouns>adjectives>verbs). Despite these differences, the overall severity of the disorder was equal between the two languages. Finally, Beaton & Davies (2007) reported three cases of deep dyslexia in three Welsh-English BWA. Among the participants, two showed differential impairment in which they produced more semantic paralexias in L2 Welsh than L1 English. The other participant, who was L1 Welsh and L2 English, showed parallel impairment, marked by equal proportions of semantic paralexias between the languages.

3.2.3. Summary

Although many of the studies in this section initially aimed to examine whether orthographic differences influence reading ability (as acknowledged in 3.2.2), their findings also revealed broader patterns of reading impairment independent of script. Several studies concluded that while orthographic differences may contribute to language-specific dyslexia markers (e.g., Béland & Mimouni, 2001), they do not appear to cause selective damage to one language or lead to different dyslexia subtypes. Instead, most studies reported differential impairment across BWA reading various scripts with evidence for consistent dyslexia subtypes in both languages. Therefore, as Goral (2019) noted, these cases of acquired dyslexia in bilinguals support the assumption of shared representations for reading that are subserved by uniform cognitive and neural systems for several reasons.

First, if there were separate systems for written language processing according to language or script, then it would be possible to observe selective impairment in which

reading in one language is damaged while the other is completely spared. Although the studies reviewed here do not directly preclude the possibility of selective impairment (given their small sample sizes and varying methodologies), none reported this profile despite different language combinations, extreme differences in scripts/alphabets, and differences in language background between case participants. Instead, all studies reported BWA with parallel and differential reading profiles in which the latter pattern was more common.

Second, although some studies reported different subtypes of dyslexia within individuals, most showed the same profile in both languages. This converging evidence is easier to account for in a shared representation model like the triangle model in which differences in orthography are learned and encoded in linguistic representations based on the depth, or the consistency between sound and spelling, of the script (Seidenberg, 1992). Damage to this framework following a brain injury alters patterns of semantic, orthographic, and phonological activation, producing similar deficits in each language that are filtered through their orthography such as greater proportion of semantic paralexias in one language over the other (i.e., Béland & Mimouni, 2001; Raman & Weekes, 2005). That is, orthographic differences can influence acquired reading behaviors but do not *determine* them, especially in individuals who read in two entirely different scripts (Beaton & Davies, 2007; Béland & Mimouni, 2001; Raman & Weekes, 2005).

Third, all three patterns of deficits with respect to L1 and L2 were observed across studies: i) better preserved L1, $L1 > L2$, ii) better preserved L2, $L2 > L1$, and iii) equal impairment, $L1 = L2$. The variability in these patterns suggests that differences in premorbid

proficiency and familiarity with reading in both languages—as some studies such as Ibrahim (2009), Ohno et al. (2002), and Weekes et al. (2007) noted—can also affect profiles of reading impairment. Again, these proficiency effects are easier to account for in a triangle model framework that assumes patterns of activation settle over time with repeated exposure and frequency of use in each language. Under this framework, shifting dominance and frequency of reading could result in the various patterns above given that L1 or L2 could be the dominant or non-dominant languages at various points in a bilingual individual’s life.

In sum, the current literature on bilingual alexia suggests that impairment profiles vary in which language may be more severely affected. Additionally, BWA are generally expected to show the same dyslexia subtype in both languages. However, key questions remain regarding the frequency and distribution of these impairment profiles in reading, how they interact with different acquired dyslexia subtypes, and whether they align with spoken language deficits—three issues that form the basis for Aim 1.

Table 3.1 Summary of Acquired Dyslexia Studies in BWA

Study	Sample	Language Combinations	Domains Tested	Key Results	Implications			
					Impairment Profile	Dyslexia Profile	L1-L2	Other
Lyman et al. (1983)	1 BWA	Chinese-L1 English-L2	Oral reading	<ul style="list-style-type: none"> Chinese reading and writing much more impaired than English 	Differential	Not reported	L2 > L1	In English, BWA used letter-by-letter strategy (not possible in Chinese) that could have signaled pure dyslexia diagnosis
Ibrahim (2009)	1 BWA	Arabic-L1 Hebrew-L2	Oral reading	<ul style="list-style-type: none"> Reading impairment greater in Hebrew than Arabic After general language therapy, both languages improved Reading only improved in Arabic 	Differential	Not reported	L1 > L2	Selective recovery for reading—only Arabic improved while Hebrew did not. L2 Hebrew more affected. During reading, BWA showed different reading strategies in both languages such as letter-by-letter reading in Arabic which is not available in Hebrew
Weekes et al. (2007)	8 BWA	Mongolian-L1 Chinese-L2	Oral reading Reading comp	<ul style="list-style-type: none"> Testing was not strict enough to determine dyslexia subtype 3/8 BWA showed more impairment in L2 Chinese No effect of script on performance 	Differential	Not reported	Some L1 > L2	Authors suggest differences in impairment are more likely due to familiarity and proficiency in reading rather than script
Ohno et al. (2002)	1 BWA	Japanese-L1 English-L2	Oral reading Reading comp	<ul style="list-style-type: none"> Post-stroke reading much worse in Japanese Japanese kana (phonologically based writing system) more impaired than kanji (logographic system) 	Differential	Pure in both	L2 > L1	More severe reading impairment in Japanese despite learning English later in life

Raman & Weekes (2005)	1 BWA	Turkish-L1 English-L2	Oral reading Reading comp	<ul style="list-style-type: none"> • BWA diagnosed with surface dyslexia in English and similar subtype in Turkish • Reported lexical reading difficulties caused by phonological deficits 	Differential	Surface in both	L1 > L2	Evidence that damage to phonological representations (and their connections with semantics) can result in surface dyslexia symptoms which is consistent with the triangle model's hypotheses
Karantk (2002)*	1 BWA	Hindi-L1 English-L2	Oral reading Reading comp	<ul style="list-style-type: none"> • Observed semantic paralexias, poor nonword reading, function word effect, and imageability effect in English • Diagnosed w/ deep dyslexia in English and 'pure' dyslexia in Hindi 	Differential	Deep in English, Pure/Glo- bal in Hindi	L2 > L1	More severe reading impairment in Hindi despite learning English later in life. Authors suggested pure dyslexia for Hindi but testing supports global dyslexia instead
Senaha & Parente (2012)	1 BWA 2 HB	Japanese-L1 Portuguese-L2	Oral reading	<ul style="list-style-type: none"> • Impaired lexical reading observed in Japanese kanji and Portuguese which suggests common locus of impairment • No script effects on performance • Relative severity of deficits similar across both languages 	Parallel	Surface in both	L1 = L2	Authors did not use terms 'parallel impairment' nor did they officially suggest surface dyslexia in Portuguese; however, results support both of these findings
Béland & Mimouni (2001)	1 BWA	Arabic-L1 French-L2	Oral reading Reading comp	<ul style="list-style-type: none"> • Deep dyslexia in both marked by lexicality, function word, and imageability effects • In French, more semantic paralexias • In Arabic, grammatical class effect and also more translation errors 	Parallel	Deep in both	L1 = L2	Comparable deep dyslexia in both languages; however, the markers of the disorder differed slightly between them, perhaps caused by orthographic differences between Arabic and French

Beaton & Davies (2007)**	3 BWA	For 2 BWA: English L1, Welsh-L2; For 1 BWA: Welsh-L1, English-L2	Oral reading comp	<ul style="list-style-type: none"> • All 3 BWA showed more semantic errors in naming than in oral reading • 2 BWA showed more semantic errors in Welsh reading, 1 showed equal proportions in English and Welsh 	2 Differential & 1 Parallel	Deep in both	2 BWA: Provides strong support for L1-English individual differences in > L2-Welsh profiles of impairment and 1 BWA: capacity for varied patterns of L1-Welsh = dyslexia among the same L2-English language combinations
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Note. Studies are presented in the order they are discussed in the text. *Key Results* briefly presents the most important findings for differences in post-injury reading performance across two languages. *Implications* denotes the overall impairment profile described in the study (i.e., differential or parallel), the subtype of acquired dyslexia (dyslexia profile), the relative degree of preserved abilities between L1 and L2, and other noteworthy findings. *The participant in Karanth (2002) was a multilingual person with aphasia who spoke five languages and read in three; the individual was only tested in reading of English and Hindi. **In Beaton & Davies (2007), the authors report the dominant and non-dominant languages rather than L1 and L2.

4. EYE TRACKING FOR READING IN APHASIA

Chapters 2 and 3 demonstrated that alexia and acquired dyslexia may be characterized by offline performance on clinical tasks that evaluate semantic, phonological, and orthographic representations post-stroke. Although offline tasks are important for assessing the connections between aphasia and alexia, the clinical interpretation of their results may be limited when used in isolation. For example, poor scores on a test of written sentence comprehension may reveal deficits when processing linguistic material beyond single words. However, it may be difficult to determine *why* an individual performed poorly on offline tasks because performance on these assessments is typically scored after—rather than during—completion.

Online methods such as eye tracking, which involve real-time measurement of linguistic processing *during* completion of some task, are increasingly being used to investigate changes in post-stroke reading in PWA (Sharma et al., 2021). These methods have recently been touted as more objective and accessible paradigms because they can capture language behaviors without requiring PWA to produce verbal responses during testing. This is important because some PWA may have limited insight into their own deficits and may struggle to identify specific aspects of their reading difficulties. On the other hand, individuals who can identify their own deficits may struggle to describe them given that aphasia reduces communication ability. Separately, eye tracking during reading may yield important clinical information to contextualize deficits. For example, eye gaze analyses may be used to reveal parts of sentences or texts that are difficult to comprehend based on whether an individual spent inordinate amounts of time focusing on one area

relative to others. Analyses may also identify strategies PWA may employ while reading such as multiple rereading or skipping certain types of words (e.g., function words like prepositions) that are harder to comprehend. In each of these cases, these reading behaviors may point to i) aspects of written stimuli that may contribute to poor performance on reading tasks and ii) (mal)adaptive strategies that PWA may adopt to manage perceived difficulties associated with post-stroke reading. For example, PWA may engage in multiple rereading to buy themselves more time for accessing the semantic, phonological, and orthographic representations necessary for word identification and comprehension.

The goal of this chapter is to review the literature on eye tracking during reading in PWA to lay the foundation for similar analyses for the Spanish-English BWA in this study. Like the PWA, the BWA are also expected to employ strategies to compensate for reading impairment post-stroke. However, unlike the PWA, the BWA must also manage activation and inhibition of their languages to enable successful comprehension during reading. Specific words and parts of sentences that have special status in the bilingual mental lexicon (e.g., cognates) are expected to influence eye gaze patterns for the BWA with important implications for the hypotheses and analyses in aim 2.

4.1. Eye Movements During Reading

Before understanding how eye gaze may be altered for PWA, it will first be necessary to review expected patterns of eye movements during reading in healthy adults. In the absence of a brain injury, adults show predictable eye gaze patterns during silent reading comprehension made up of *saccades*, or high velocity eye movements that characterize shifts in visual processing (Rayner, 1998). Because visual sensitivity is

reduced during eye movements, individuals do not take in new information during saccades. Instead, new information is learned when the eyes pause, or fixate, on words or letters between saccades. *Fixations* during silent reading typically last between 200-300 milliseconds (ms) and are often preceded by saccades of 2° which represents a viewing angle of about 8 letters. Saccades between fixations are typically 1-15 letters in length and may provide insight into cognitive effort during reading. For example, saccades that are relatively short—only a few letters in length—suggest letter-by-letter reading of an unfamiliar word. Longer saccades may suggest an individual is recognizing whole words and skipping some during fluent reading; in fact, neurotypical adults tend to skip words that are short and/or have low semantic content such as determiners (Carpenter & Just, 1983; Drieghe et al., 2005; Rayner, 1998; Rayner & Duffy, 1988).

In languages like Spanish and English, most saccades proceed left-to-right; however, not all eye movements follow this pattern. About 10-15% of all saccades proceed backwards, towards letters or words that have already been read (Rayner, 1998). These *regressions* are typically a few letters in length and may signal different behaviors during silent reading. For example, short regressions to the left may be necessary to correct a forward saccade that overshot an upcoming word in the sentence by a few letters. By contrast, short within-word regressions or longer regressions to an earlier part of a sentence suggest the reader had trouble comprehending something on the first pass through a word or sentence. In these cases, fluent readers are adept at identifying and returning to earlier locations that caused them difficulty (Frazier & Rayner, 1982) whereas struggling readers engage in less precise backtracking such as returning to the very beginning of a sentence

(Murray & Kennedy, 1988).

Overall, it is important to distinguish eye movements that are likely to result from imprecise visual control and those that index comprehension difficulties to avoid incorrect conclusions about the nature of any reading difficulties. Several eye tracking measures are available to examine reading behaviors over the time course of written language processing. Typically, these measures are classified based on whether they capture early processing attempts that are likely to occur on a *first pass* through the sentence or later processing attempts on *successive passes* through the sentence. As we will see below, early and late processing measures are important for documenting specific reading behaviors related to the time course of lexical access and the integration of meaning as adults read material at the sentence level and beyond. Table 4.1 provides common measures used in eye tracking during reading studies along with their definitions and classifications.

Table 4.1 Summary of Common Eye Tracking Measures for Reading

Measure	Processing Stage	Definition
First Fixation Duration	Early	Duration (elapsed time) of the first eye fixation on target word
Gaze Duration	Early	Sum of all first-pass fixations to target word before eyes leave target and move left or right
Skipping Rate/Probability	Early	Likelihood that a target is never fixated during first pass reading
Probability of First Pass Fixation	Early	Likelihood that a target is fixated during first pass reading
Probability of First Pass Regression	Early	Likelihood that a regression towards the target is detected in first pass reading
Go-past Time	Late	Sum of all fixation durations from moment eyes first land on the target until they move to the right of the word, including any regressive movements to left of target
Rereading Time	Late	Sum of all refixations to the target word after regressions in to target
Total Reading Time	Late*	Sum of all fixations and refixations to the target word
Number/Average Number of Fixations	Indeterminate	Raw (or average) count of fixations to the target word across all pre-defined regions in a sentence

Number/Average Number of Regressions	Indeterminate	Raw (or average) count of regressions to the target word across all pre-defined regions in a sentence
Saccade Amplitude	Indeterminate	Average number of letter spaces moved during reading across pre-defined sentence regions

Note. The table represents one possible name for each measure although several may have different labels across studies. For example, Total Reading Time may also be referred to as Total Fixation Duration or Total Summed Fixation Duration. Some measures may be indeterminate based on if they conflate first pass reading and rereading or do not distinguish between stages such as Saccade Amplitude. *Total Reading Time may be indeterminate as well if no measure of rereading or first fixation duration (or the like) is included in a design to subtract out this information from Total Reading.

4.2. Eye Tracking During Reading in PWA

Many previous studies that have used eye tracking to examine post-stroke oral reading (Ablinger et al., 2014; Schattka et al., 2010) and silent reading comprehension abilities (DeDe, 2017; 2020; DeDe & Kelleher, 2021; Hsu et al., 2014; Huck et al., 2017a; 2017b; Hux et al., 2025; Kim & Bolger, 2020; Knilans & DeDe, 2015; Knollman-Porter et al., 2023; Smith et al., 2018) have revealed consistent behavioral differences between PWA and healthy controls (HC). In the context of aphasia, these differences may arise due to delays in lexical access (i.e., lexical information is not available when needed; Ferrill et al., 2012; Love et al., 2008) or difficulties with lexical integration (i.e., trouble incorporating the meaning of a word into the unfolding sentence context; Dickey et al., 2007; Thompson & Choy, 2009). Due to these sources of impairment, PWA may demonstrate expected patterns of lexical and semantic/syntactic processing in sentences (e.g., a lexical frequency effect); however, relative to HC, PWA effects: 1) may be exaggerated (i.e., greater magnitude in reading time); 2) may be delayed and emerge slower across the expected time course of lexical processing; and 3) may persist for longer (i.e., during rereading or reanalysis).

In their 2015 study, Knilans and DeDe observed significant differences between PWA and HC when reading subject and object cleft sentences. Eye tracking during reading analyses showed exaggerated reading times at the main verb and relative clause pronoun for PWA when compared to HC. Additionally, these exaggerated lexical effects emerged later for the PWA than they did for the HC (i.e., they were delayed) and they persisted for longer as captured by inflated rereading and total reading time differences. These findings led Knilans and DeDe to propose a two-tier strategy of reading: the eye gaze patterns of the PWA suggested that they were engaged in lexical retrieval in the first pass through a sentence and syntactic processing in successive passes to give themselves more time to comprehend each sentence. This finding was consistent with the Lexical Integration Deficit Hypothesis (LIDH; Thompson & Choy, 2009) that contends that the construction of meaning during comprehension tasks is significantly delayed in PWA.

DeDe (2017) observed similar patterns of reading differences between PWA and HC. In this study, the PWA showed exaggerated effects of word frequency (i.e., more frequent words are associated with faster and more accurate sentence comprehension) and word length in early processing eye tracking measures, signaling shorter processing times for high frequency and short words—compared to low frequency and long words, respectively—than did the HC. Crucially, these effects emerged early in the time course of processing and the PWA remained sensitive to them as captured by differences in rereading times (e.g., the PWA reread high frequency words less often than low frequency words). These results also provided support for a two-tier system of processing as proposed in Knilans and DeDe (2015).

Other studies have also observed exaggerated lexical effects in reading tasks for PWA. However, the effects do not always emerge on a delayed time course nor persist for longer compared to HC. For example, Kim and Bolger (2020) showed that PWA had longer gaze durations and more regressions across (un)predictable sentences although these exaggerated processing effects did not emerge later or persist for longer compared to HC. Johnson and Rayner (2007) reported exaggerated effects of word frequency and word predictability for PWA—effects that also did not emerge later or persist for longer relative to HC patterns reported in the literature (this was a single case study). DeDe (2020) also noted exaggerated lexical effects for the PWA in her study but did not observe any other time course differences with control participants. The departure of these results from the previous studies could be partially explained by study design. None of these three included rereading time as an eye tracking measure that was crucial for observing delayed and persisting effects in Knilans and DeDe (2015) and DeDe (2017). Additionally, Johnson and Rayner (2007) was a single case study that employed a self-paced reading paradigm in which their participant could not reread words. DeDe (2020) examined perceptual span in PWA using a gaze-contingent moving windows design that was not directly focused on potential differences in the time course of processing.

Beyond the sentence level, other studies have reported similar patterns—namely that PWA showed exaggerated effects compared to HC—which suggests that this behavior occurs across levels of linguistic complexity. For example, Smith et al. (2018) showed that 24 PWA had shorter saccade amplitudes and significantly longer fixation durations than 24 HC when reading short passages and pseudo-passages (i.e., they did not contain

recognizable English words). In another study, 9 PWA read short narratives in two conditions: a reading only condition and a reading with text-to-speech condition (Knollman-Porter et al., 2023). Compared to HC, the PWA had significantly more forward fixations, regressions, and off-track fixations across the narratives suggesting that the PWA were spent longer during first-pass reading and rereading. In a similar study, 5 PWA from Hux et al. (2024) showed significantly longer fixation durations during passage reading; crucially, these exaggerated effects also emerged on a more delayed time course than expected based on the HC data.

A separate set of studies have shown that PWA can exhibit similar (i.e., not exaggerated) lexical effects to HC; however, these effects may be delayed and/or may persist for longer in (re)reading. For example, Huck et al., (2017a) reported that their PWA showed a delayed word frequency effect that was similar in magnitude to that of their HC. Huck et al. (2017b) demonstrated similar findings in which PWA showed delayed but commensurate ambiguity resolution effects when reading polysemous verbs relative to HC. Hsu et al. (2014) again reported similar lexical effects between PWA and HC when reading sentences with a pronoun-antecedent match/mismatch. While their HC showed sensitivity to the mismatch at the critical region (i.e., part with the mismatch), the PWA showed this effect at a spillover region immediately after the critical region. Finally, DeDe and Kelleher (2021) pointed to delayed integration of animacy information and sentence predictability cues that persisted over the time course of reading for their PWA. These same effects occurred much earlier for the HC and resolved quickly (i.e., were not captured in rereading measures).

Overall, eye tracking studies have indicated that while PWA are sensitive to the same word—and sentence-level factors as HC during silent reading, the time course of processing varies considerably between the groups. In some cases, PWA have shown: 1) exaggerated effects in which the difference in reading time for two categories of words is much larger compared to HC; 2) delayed effects in which expected reading behaviors occur much later in the time course compared to HC; and 3) persisting effects in which expected reading behaviors endure for PWA long after they have dissipated for HC. These patterns highlight the variability in how PWA engage with silent reading comprehension, providing insight into how stroke alters the time course of word- and sentence-level processing.

Given these group-level differences, previous studies have also examined how individual factors, such as aphasia severity and type, contribute to variability in reading behavior. Recent evidence from both DeDe and Kelleher (2021) and Smith et al. (2018) suggests the time course of lexical processing is influenced by aphasia severity and aphasia subtype such that milder impairment and profiles with less reading impairment (e.g., anomic aphasia compared to Wernicke’s or Brocas’s) are associated with *larger* lexical effects and *faster* reading times. PWA may also demonstrate individual differences in reading behaviors and self-adopted strategies for reading post-stroke. Both Knollman-Porter et al. (2023) and Hux et al. (2024) reported on PWA who varied in their similarity to HC based on eye gaze patterns. Nevertheless, even those PWA who patterned more closely with HC still showed significantly different reading times and behaviors across short texts such as reduced probability of skipping words and greater numbers of fixations and longer fixation durations compared to HC.

4.3. Summary

In sum, eye tracking studies have revealed various eye gaze patterns that index reading difficulties in PWA and distinguish them from HC during silent reading comprehension. In general, PWA produce more fixations, skip fewer words, and engage in more rereading overall compared to age-matched HC which may be related to delays in lexical access or lexical integration. More specifically, PWA may demonstrate expected patterns of lexical activation such as word frequency effects in sentences; however, these effects may be more exaggerated (i.e., greater magnitude) than in HC; they may emerge slower across both early and later processing measures; and they may persist for longer as captured by inflated rereading or total reading times. These findings provide direct support for an altered time course of processing in PWA that is consistent with the Lexical Integration Deficit Hypothesis. Additionally, some of the results support Knilans and DeDe's (2015) two-tier theory of sentence comprehension while others notably do not (e.g., Huck et al., 2017; Kim & Bolger, 2020). Finally, there is emerging evidence that aphasia subtype and/or severity may affect eye gaze patterns among PWA. These findings suggest that PWA, and by extension BWA, are likely to demonstrate a variety of eye gaze patterns that point to impaired silent reading post-stroke—patterns that have important implications for Aim 2. The studies reviewed in this section are summarized in Table 4.2.

Table 4.2 Summary of Eye Tracking During Reading Studies in PWA

Study	Sample	Design & Stimuli	Eye Tracking Measures	Key Results	Implications			
					EE	DE	PE	Other
Knilians & DeDe (2015)	9 PWA 8 HC	<i>Eye tracking during reading</i> Sentences: 1) 24 subject clefts, 24 object clefts 2) 176 fillers	1) Gaze duration 2) Go-past time 3) Rereading time 4) Total reading time	<ul style="list-style-type: none"> Relative to HC, PWA showed significantly exaggerated rereading and total reading times at the main verb and relative clause PWA showed a pattern of focusing on lexical retrieval in the first-pass through a sentence and syntactic processing in the second-pass 	X	X	X	Strong support for the Lexical Integration Deficit Hypothesis (LIDH): PWA show delayed processing effects, and these effects persisted for longer than in HC
DeDe (2017)	9 PWA 8 HC	<i>Eye tracking during reading</i> Sentences: 1) 24/24 subject/object clefts 2) 27/27 (in)transitives 3) 21/21 high/low freq 4) 80 simple/complex	1) First Fixation Duration 2) Gaze Duration 3) Skipping Rate 4) Rereading Time	<ul style="list-style-type: none"> Relative to HC, PWA showed magnified lexical effects (word frequency and length) in early processing measures, and some persisted in rereading times PWA skipped words far less often than HC 	X		X	Supports Knilians & DeDe's (2015) theory of two-tiered processing strategy
Kim & Bolger (2020)*	10 PWA 8 HC	<i>Eye tracking during reading</i> Sentences: 1) 40/40 nouns in high/low predictability sentences	1) Gaze duration 2) Number of regressions 3) Whole sentence measures	<ul style="list-style-type: none"> PWA showed longer gaze durations and more regressions across sentences compared to HC (i.e., magnified effects) 	X			Predictability effects emerging in gaze durations does not support DeDe's views about two-stage processing
Johnson & Rayner (2007)	1 PWA	<i>Eye tracking during reading</i> Sentences: 1) 15/15 high/low freq 2) 14/14 predictable/unpredictable	1) Number of fixations 2) Total fixation duration	<ul style="list-style-type: none"> PWA showed expected but magnified effects of word frequency and predictability based on HC patterns in literature Word frequency effect was 12-244% stronger and unpredictability was 4-13 times stronger 		X		
DeDe (2020)	11 PWA 15 HC	<i>Eye tracking during reading w/ gaze-contingent moving windows</i> Sentences 20/20/20/20:	1) Fixation time 2) Fixation error	<ul style="list-style-type: none"> PWA had intact oculomotor processing but still demonstrated reduced perceptual span W+1 relative to controls, W+2 	X			Brain injury may result in a more focused mental viewing window that

			<p>1) whole sent visible [W] 2) current word & 1 to left [1W] 3) current word & 1 to left & 1 to right [W+1] 4) current word & 1 to left & 2 to right [W+2]</p>				is at least partially responsible for greater number of fixations and less skipping for PWA relative to HC
	Smith et al. (2018)	24 PWA 24 HC	<p><i>Eye tracking during reading</i> Texts: 1) 70 texts for reading and pseudo-reading 2) 40-60 words, 8th grade reading level</p>	<p>1) Total fixation duration 2) Saccade amplitude</p>	<ul style="list-style-type: none"> Compared to HC, PWA showed smaller saccade amplitudes and longer fixation durations in text reading PWA w/ anomic aphasia (less severe) showed the smallest saccade amplitudes out of all PWA—related to careful reading strategies 	X	PWA may show individual differences in reading based on aphasia characteristics
	Knollman-Porter et al. (2023)	9 PWA 9 HC	<p><i>Eye tracking during reading</i> Texts: 1) 20 narratives, same as Hux et al. (2024) 2) 2 conditions: reading only and reading w/ text-to-speech</p>	<p>1) Average number of forward fixations 2) Average number of regressions 3) Average number of off-track fixations</p>	<ul style="list-style-type: none"> In the reading only condition, PWA showed significantly more fixations across 3 measures compared to HC 	X	Text-to-speech reduced average fixations across the 3 measures, but PWA still differed from HC significantly
	Hux et al. (2024)	5 PWA 5 HC	<p><i>Eye tracking during reading</i> Texts: 1) 20 passages and 1 practice 2) 5-6 sentences each, 67-73 words</p>	<p>1) Average fixation duration 2) Average summed duration on initial attempts 3) Total summed fixation duration on all attempts</p>	<ul style="list-style-type: none"> All PWA read passages significantly slower compared to HC PWA rarely skipped words (only ~20% words for least severe) whereas HC group skipped often (~80% of all words) 	X X	PWA may show individual differences in reading behaviors related to brain injury and self-adopted strategies for reading
	Huck et al. (2017a)	17 PWA 20 HC	<p><i>Eye tracking during reading</i> Sentences: 1) 14/14 high/low frequency words into 14/14 high/low predictability sentences 2) 2 lists w/ 28 experimental, 31 fillers, 5 practice</p>	<p>1) Gaze duration 2) Total reading time 3) Probability of first-pass regression 4) Probability of first-pass fixation</p>	<ul style="list-style-type: none"> Compared to HC: <ul style="list-style-type: none"> PWA ~10% less accurate on comprehension questions after sentences PWA skipped words significantly less often 	X	Results do not directly support Knilans & DeDe (2015) and DeDe (2017)

				<ul style="list-style-type: none"> • Unlike other studies, PWA did not show magnified frequency effects in PWA compared to HC • Less severe PWA showed weaker frequency effects in total reading time 			
Huck et al. (2017b)	11 PWA 11 HC	<i>Eye tracking during reading</i> Sentences: 1) 10 polysemous verbs (e.g., recognize) in 4 conditions 2) 2 lists w/ 20 experimental sentences and 30 fillers	1) First fixation duration 2) Gaze duration 3) Total fixation duration 3) First-pass regression	<ul style="list-style-type: none"> • Overall, PWA showed similar processing patterns to HC but effects were slower to emerge (delayed) • Less severe PWA had reduced ambiguity effects in gaze duration 	X		
Hsu et al. (2014)*	6 PWA 15 HC	<i>Self-paced reading</i> Sentences: 1) 40 sets of 8 sentences w/ pronoun-antecedent match/mismatch 2) 160 fillers	1) First fixation duration 2) First pass reading time 3) Regression-path 4) Second pass reading time	<ul style="list-style-type: none"> • PWA showed similar processing effects as HC; however, processing times were delayed; HC showed sensitivity at critical region whereas PWA showed mismatch effect at spillover region 	X	X	Supports LIDH
DeDe & Kelleher (2021)	11 PWA 24 YHA 24 OHA	<i>Eye tracking during reading</i> Sentences: 1) 24 quartets w/ animate and inanimate subjects in subject/object relatives 2) 6 lists of 16 experimental items and 80 fillers	1) Gaze duration 2) Go-past time 3) Rereading time	<ul style="list-style-type: none"> • PWA showed delayed integration of animacy and sentence predictability and were less accurate on comprehension questions relative to HC • PWA showed similar effects to OHA; however, effects emerged later (were delayed) and persisted for longer 	X	X	

Note. Studies are presented in the order they are discussed in the text grouped by the implications section of the table. *Key results* briefly presents the most important findings for differences in reading behavior between PWA and HC. *Implications* denotes whether PWA showed exaggerated effects (EE), delayed effects (DE), and/or persisting effects (PE) over the time course of processing compared to HC. *Other Implications* denote additional findings relevant to theories of processing or individual differences in reading behavior. *Hsu et al. (2014) is the only study to use a used self-paced reading paradigm instead of eye tracking during reading

5. READING IN BILINGUAL INDIVIDUALS

In Chapters 2-4, we introduced models of reading and reading impairment, traced profiles of alexia and acquired dyslexia in MWA and BWA, and demonstrated how eye tracking during reading may be used to contextualize reading post-stroke and supplement traditional offline clinical testing. Now, we turn our attention to some residual considerations for reading in bilingual individuals that is necessary to finalize the research questions and hypotheses across Aims 1 & 2. This chapter will introduce the principal model of bilingual reading alongside important cognitive-linguistic mechanisms that support language processing in bilinguals. Then, it will review specific stimuli for bilingual individuals and conclude with eye tracking evidence that links models of processing with reading comprehension behaviors.

5.1. The Bilingual Interactive Activation Plus Model

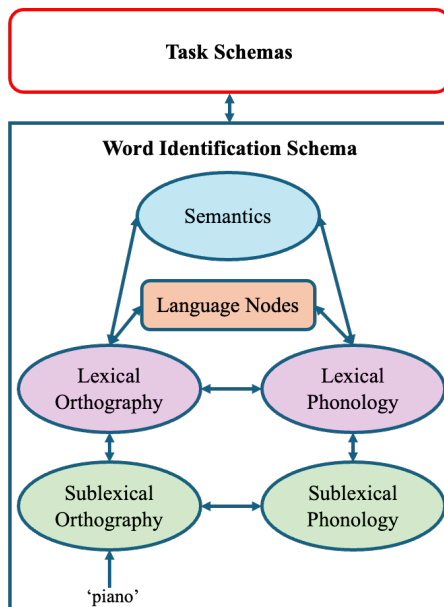
In healthy bilinguals, reading comprehension proceeds in a language non-selective manner in which both languages are activated in parallel, and some mechanism of language selection must be employed to finish reading successfully in the target language (de Groot et al., 2000; Kroll et al., 2006). Bilingual word recognition models such as the Bilingual Interactive Activation Plus (BIA+) Model (Dijkstra & van Heuven, 1998; 2002) and its computational implementation, MULTILINK (Dijkstra et al., 2019) contend that this pattern of language non-selective access occurs—even in unilingual contexts (e.g., novel in English)—because visual information must be constantly matched to mental representations in an integrated bilingual lexicon (Duyck et al., 2007). In the BIA+ model, resolving competition between languages during reading comprehension or oral reading is

a top-down process by which linguistic representations in one language are selectively boosted while those in the other are inhibited (Grainger et al., 2010). Specific language nodes in the model oversee this precise tuning of activation by integrating contextual information from the language environment and bottom-up processing cues from the written stimulus (i.e., orthography and phonology) to determine the probability that a word belongs to one language over the other. The computation of these probabilities unfolds over time for each word in a sentence or paragraph to manage reading more complex material as well. Under this framework, only representations in the target language will remain activated; however, it is important to note that the other, non-target language can never be “turned off.”

Let’s illustrate these model principles with an example of a healthy Spanish-English bilingual adult reading the word, “piano” based on the BIA+ architecture shown in Figure 5.1. In the first stages of visual processing, the bilingual adult will recognize the sublexical orthographic features that encode the letters p-i-a-n-o. Sublexical orthographic representations activate sublexical phonological features (e.g., contours of the letter ‘p’ activate phonological features such as [+consonantal] of the phoneme /p/) and lexical orthographic entries—or the visual word form ‘piano’—in tandem. This pattern continues with sublexical phonological and lexical orthographic information flowing to lexical phonology to activate the sound form of the word (/piænoʊ/). At this stage of processing, a neighborhood or competitor set of words (see Figure 5.2) is produced based on spreading activation from the sublexical to lexical levels in both orthography and phonology. In the BIA+ model, there are no separate lexicons so, this competitor set contains entries that

overlap in phonology and orthography between English and Spanish. Therefore, the competitor set for ‘piano’ would include words like ‘party’ in English and *piano* in Spanish. This brings us to an important point that will be addressed again in section 5.2: *piano* is a cognate between English and Spanish, or words that share some degree of orthographic and semantic representations across languages. Figure 5.2 demonstrates that cognates have special status in the bilingual lexicon given the stronger connections between sublexical and lexical features between the languages than may be observed for two words in the same language (e.g., ‘party’ in English). Because ‘piano’ is recognized as a word in both languages, reading it and comprehending it occur much faster than for a word like ‘party’ whose Spanish translation, *fiesta*, has much fewer sublexical and lexical overlapping features.

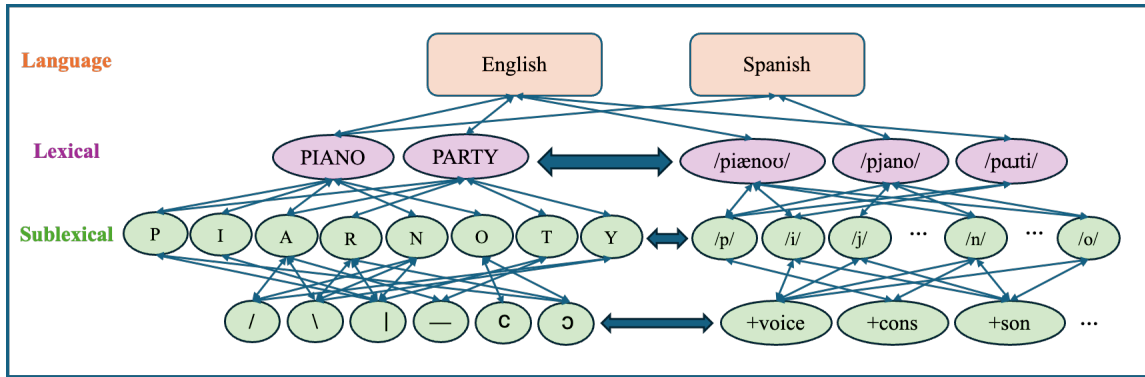
Figure 5.1 The Bilingual Interactive Activation Plus Model



Caption. The overall framework of Dijkstra and van Heuven (2002)’s Bilingual Interactive Activation Plus Model is shown. The word identification schema enables word recognition and decoding for oral reading in two languages. Task schemas including lexical decision,

written word-picture matching, etc. Bidirectional arrows throughout the system represent feed-forward and feedback loops of linguistic activation.

Figure 5.2 Cohort Activation Model



Caption. An example of the cohort activation for the word ‘piano’ is shown. Visual processing of ‘piano’ activates sublexical features in orthography and phonology. This activation flows to related word works at the lexical level and finally to language nodes.

Resolving the sheer amount of competition produced by spreading activation throughout levels in this framework is accomplished by multiple mechanisms. First, a series of bidirectional connections between each level of processing is hypothesized such that converging activation at higher levels conveys inhibition in a feedback loop to lower levels of activation. For example, as activation converges on ‘piano’ in our example, the levels of activation for the letter ‘r’, the associated sound, and their sublexical features are inhibited to reduce the likelihood that a word like ‘party’ is ultimately selected. Second, the activation of ‘party’ would be further constrained by within-language inhibition (Grainger et al., 2010) such that increasing activation for the orthographic form ‘piano’ directly down-regulates ‘party’ in English and *fiesta* in Spanish given that these neighbors compete at the same level. Finally, top-down inhibition from the language nodes and task schemas constrains the selected word. The language nodes provide asymmetric constraints

on wordforms that are more likely to be tagged as belonging to the non-target language based on converging activation onto the target language node. The task schemas encode step-by-step information about specific reading tasks (i.e., written synonym judgment) as well as contextual information about the language environment. For example, a bilingual individual may complete a reading comprehension activity much faster if they are aware all stimuli will be in English rather than English and Spanish. In these scenarios, some Spanish activation is still expected and cannot be avoided, even if the bilingual is not consciously aware of this cross-language influence during reading (Grainger & Beauvillain, 1987; Thierry & Wu, 2007; Thomas & Allport, 2000; von Studnitz & Green, 1997).

5.2. Word-level and Sentence-level Effects in Bilingual Reading

A wealth of literature has revealed that the speed and efficiency of processing in the BIA+ framework can be influenced by various word-level (lexical) and sentence-level factors. These findings are broadly consistent with the bottom-up and top-down cues presented in the section 5.1 that both contribute to accurate word selection and recognition. This section will focus on the evidence from offline tasks that have uncovered specific lexical influences on bilingual word recognition as well as the eye tracking evidence that has captured both lexical and sentence-level effects on reading comprehension overall.

5.2.1. Offline Tasks and Lexical Effects

Crucially, it has been proposed that parallel activation and therefore processing speed (i.e., reading times) may be influenced by lexical information such as words stored

in the lexicon that have overlapping orthographic, phonological, and/or semantic features. In fact, early evidence for non-selective language activation came from studies that observed faster reading times in a single word context in L2 (Carramazza & Brones, 1979) for cognate words like ‘piano’. This *cognate facilitation effect* has since been observed across studies (Dijkstra et al., 2010; Voga & Grainger, 2007) and suggests that faster processing times for cognates occur because activation for two words that share orthographic features across languages, converges more readily on a single semantic representation (Dijkstra et al., 2019). By contrast, healthy bilinguals appear to show slower reading times when reading interlingual homographs (e.g., *fin*, end in Spanish and an animal part in English), or words that share orthography but diverge in meaning across languages (Beauvillain & Grainger 1987; de Groot et al., 2000; Dijkstra et al., 1999; Dijkstra et al., 2000). This *homograph interference effect* suggests that bilingual individuals incur processing costs during L2 reading when they encounter a word that has separate meanings as they must spend longer suppressing one meaning (e.g., word meaning in L1) to integrate the word within the unfolding sentence context.

Taken together, findings from offline tasks demonstrate that bilingual word recognition is strongly influenced by lexical properties such as orthographic and phonological overlap across languages. Cognate words consistently facilitate processing due to shared representations across the bilingual lexicon while homographs introduce interference, requiring additional processing time to resolve ambiguity in meaning. However, these effects have primarily been studied in isolated word tasks which do not account for the influence of broader sentence context on bilingual reading. Given that

sentence-level cues can serve as additional constraints on lexical selection, eye-tracking methods may offer a more fine-grained approach to examine how bilinguals integrate lexical and contextual information over time than isolated tasks alone—a topic that is explored in the next section.

5.2.2. Eye Tracking Tasks and Sentence-level Effects

The BIA+ model posits that cognate facilitation and homograph interference effects should be weaker when reading at the sentence-level than would be expected for reading single words. This is because the surrounding sentence context would naturally constrain lexical selection and assist bilinguals with constructing the overall meaning of a sentence. Eye tracking designs in bilingual sentence comprehension have provided an ecologically valid method for testing these model predictions. Most studies have employed both lexical and sentence-level manipulations to determine whether healthy bilinguals are sensitive to both types of information—that is, if they are aware of both word-level and sentence-level cues during silent reading comprehension. Across studies, lexical cues have included both cognates and homographs to examine whether these words elicit facilitation and interference effects when reading sentences while sentence-level cues have included a contextual manipulation such as semantic constraint, or the degree to which the sentence frame before a target word biases the prediction of that word. Evidence for the interaction of these effects is mixed; some studies report that lexical effects disappear when cognates or homographs appear in highly constrained sentences but not in loosely (low) constrained sentences (Libben & Titone, 2009; Schwartz & Kroll, 2006) and others contend that word-level effects persist across a time course of processing (van Assche et al., 2011).

For example, in their 2006 study, Schwartz and Kroll focused on examining whether semantic constraint could attenuate the effects of cognate facilitation and homograph interference during L2 sentence reading for two separate groups of Spanish-English healthy bilinguals. In a time-locked design, the authors asked bilinguals to read sentences in L2 English in which only one word was visible at a time (shown for 250 ms). Participants were further instructed to read aloud a word on the screen that would appear in red within each sentence. Sentence stimuli included 22 Spanish-English cognates, homographs and frequency and length-matched control words embedded in high and low-constraint sentences to investigate the interactions between lexical access and sentence context. Curiously, their participants did not show facilitation effects (i.e., faster reading times and/or lower error rates) when reading cognates in highly constrained sentences, suggesting that semantic context could modulate cross-language activation. In the low constraint sentences, participants did read cognates much faster than matched control words, again demonstrating that in the absence of sufficient semantic context, lexical factors such as overlapping orthographic structure could support more efficient bilingual processing. However, the same patterns were not observed for the homograph stimuli; participants did not show sensitivity to these stimuli in either sentence condition in reaction time data.

In a related study, Libben and Titone (2009) also investigated cognate facilitation and homograph interference effects in sentence context. Using an eye tracking during reading design, they showed high and low constraint sentences with either cognates, homographs, or matched control words to French-English bilinguals and asked them to

read silently for comprehension. Their results largely mirrored those of Schwartz and Kroll (2006) but the addition of eye tracking to their experimental design allowed for a more sensitive analysis of the interaction between lexical access and sentence context over the time course of processing. Cognates were read much faster than matched control words across both high and low constraint sentences in early stages of lexical processing, indexed by eye movement measures such as first fixation duration and gaze duration. In later stages of processing, a dissociation emerged in which cognates were still read faster than control words but only in the low constraint sentences. The facilitation effect disappeared in high constraint sentences as indexed by later processing measures such as go-past time and total reading time. The homograph results were entirely consistent with the cognate patterns but the relationship with reading time was opposite. Homographs were read slower than control words across sentence types in early stages of processing. In later stages, homographs were read slower than control words but only in low constraint sentences. Overall, these results indicated that healthy bilinguals are sensitive to both lexical and semantic factors during silent reading comprehension; however, either effect of lexical access—whether facilitation or interference—only persists when sentence context is low in later stages of processing. The authors explained these patterns by positing that high semantic context pre-activates language nodes in the BIA+ framework and that this activation constrains lexical expectations. These two factors give rise to the non-selective nature of sentence processing as captured by the early eye tracking measures. However, in later stages of processing, pre-activation of the language nodes caused by high semantic context speeds access and reduces the need for lexical cues in reading and the facilitation and interference

effects are no longer significant (Altarriba et al., 1996; Duyck et al., 2007). In low constraint sentences, then, there is less pre-activation at the language nodes and non-selective access must be resolved later in the time course of processing as captured by significant differences in the later eye tracking measures.

5.3. Summary

In sum, the literature in this chapter proposes a strong framework for written language processing in healthy bilinguals. Given that both languages are active even in unilingual environments, reading in bilinguals may be described as a constant process of generating word representations in each language and resolving the ensuing competition between them. Crucially, it remains unclear to what extent stroke may impact the overall integrity of this written language processing network in BWA. Similar studies about non-selective language processing in offline tasks are not available in the bilingual aphasia literature which compromises assessment and treatment of reading deficits post-stroke. Furthermore, although cognate facilitation and homograph interference effects are robust findings in the healthy bilingual literature, it is currently unknown to what extent these patterns of lexical processing during silent reading may hold for BWA. Given the nature of lexical-semantic impairment in aphasia, it is unclear if semantic constraint may modulate bilingual lexical effects for BWA, especially as a sentence-level cue to support comprehension (i.e., whether high semantic constraint and cognate facilitation could have a synergistic effect on reading in aphasia).

6. RATIONALE, AIMS, & HYPOTHESES

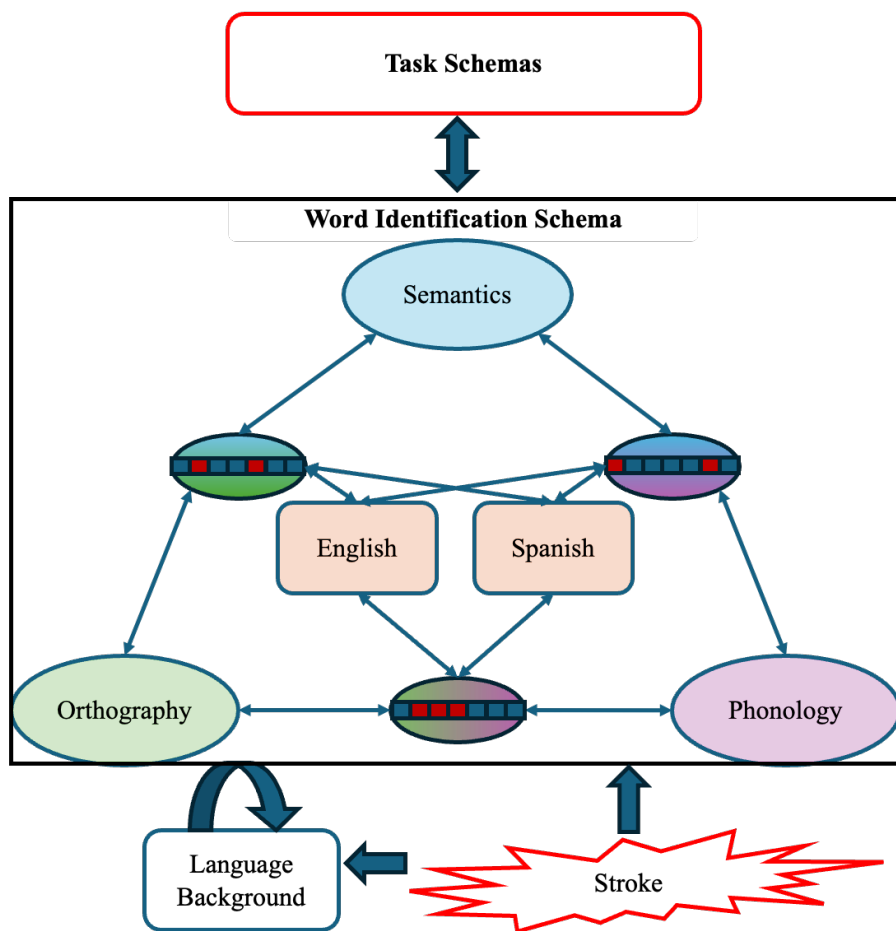
6.1. Rationale

To address the issues in the current literature raised throughout Chapters 2-5, the proposed study investigated how reading abilities change as a function of left-hemisphere stroke in a population of Spanish-English BWA. This relationship between linguistic performance and post-stroke impairment was examined using offline clinical measures of reading and eye tracking analyses to characterize profiles of alexia and acquired dyslexia. The overarching hypotheses of this work were that BWA would demonstrate abnormal reading of both words and sentences relative to BNC and that patterns of impairment across participants and languages would be modulated by pre-morbid language experience and altered patterns of language co-activation.

The key aspects of these hypotheses are captured by the Bilingual Interactive Activation for Aphasia (BIAA) Model proposed in Figure 6.1—an integrated framework that combines the structure of triangle model in Chapter 2 and the BIA+ Model in Chapter 5 to account for reading changes among BWA. The BIAA model predominately adopts the structure of the triangle model and assumes that three primary systems—semantics, phonology, and orthography—work in concert to support language processing. Like the BIA+ Model, this BIAA Model does not posit separate lexicons for L1 and L2; instead, linguistic activation throughout the system proceeds via feedforward and feedback loops that focus activity onto appropriate words in a target language in the word identification system. Individual feature units include semantic features, phones and phonetic features, and letters and visual features represented in the central processing units. Interactivity

between activated units in these central components occurs in the interfaces between them and eventually synapses onto the language nodes, represented by English and Spanish in Figure 6.1, that amplify and constrain patterns of activation as word identification and selection unfold over time (i.e., allowing for one language to win over the other).

Figure 6.1 The Bilingual Interactive Activation for Aphasia Model



Caption. The BIAA Model informed by the BIA+ Model (Dijkstra & van Heuven, 1998; 2002) and the Triangle Model (Seidenberg & McClelland, 1989). The model is completely interactive and assumes processing in bilinguals proceeds in a non-selective manner in which both languages are activated in parallel. Stroke and changes in bilingual background and experience may alter resting levels of activation throughout the model. Orange nodes in the interface levels present example patterns of activation during some reading task.

Additionally, task schemas are included like those in the BIA+ Model; these step-by-step codes are necessary to account for a variety of reading strategies including bilingual-specific ones such as recognizing words in one language and directly translating them into the other. Finally, the Model includes two aspects that are fundamental to understanding language processing in BWA: language background and the extent of stroke damage. Language background forms a reciprocal relationship with the overall word identification system in the BIAA Model: as the frequency of language use and exposure shifts over the lifespan, resting activation levels of linguistic nodes may change as well. Stroke knocks out semantic, phonological, and/or orthographic representations and introduces noise to the system that alters expected patterns of lexical activation. Stroke-induced aphasia may even alter language use patterns and exposure such that a more severely affected language may be used less after brain injury, resulting in further changes to linguistic representations based on bilingual experience.

Importantly, the BIAA Model provides a useful framework for motivating the aims across this work. Across language tasks, BWA are expected to activate cohorts or neighborhoods of words in both languages and employ selection mechanisms to finish with an appropriate target word during reading tasks; however, post-stroke language impairment will naturally alter the semantic, orthographic, and phonological representations specified by the BIAA Model, leading to abnormal patterns of language processing. Aim 1 investigated these hypothesized patterns of abnormal language processing by examining the performance of BWA on written language and spoken language tasks between Spanish and English to identify overall profiles of alexia and subtypes of acquired dyslexia in both

languages. Aim 2 determined to what extent stroke alters expected patterns of bilingual lexical access during reading by examining cognate facilitation and homograph interference effects during sentence reading.

6.2. Aim 1: To Examine Patterns of Alexia and Acquired Dyslexia in aphasia

As discussed in Chapter 3, alexia in individuals with aphasia varies in severity and subtype, although phonological dyslexia has emerged as the most common profile in MWA based on previous studies. Furthermore, reading deficits are often commensurate with spoken language impairment, suggesting shared phonological and semantic processing mechanisms across modalities. In BWA, reading impairment is further shaped by bilingual language experience and cross-linguistic factors. While case studies indicate that BWA may exhibit parallel or differential impairment patterns across languages, the distribution of alexia subtypes and the relationship between spoken and written deficits in this population remain unclear. Additionally, it is unknown how phonological and orthographic overlap between languages modulates reading outcomes post-stroke. Aim 1 addresses these gaps by systematically examining reading impairment profiles, cross-linguistic differences, and the interaction between spoken and written deficits in Spanish-English BWA.

6.2.1. Aim 1.1.

To what extent do the severity and frequency of alexia and acquired dyslexia in individuals with aphasia differ across bilingual and monolingual speakers?

Hypotheses. Relative to their respective neurological control groups, both the BWA and MWA were expected to show reduced reading accuracy and patterns of impairment consistent with subtypes of acquired dyslexia after controlling for age, education, and pre-stroke reading ability. These impairments are hypothesized to reflect disruption to modality-independent language systems that support orthographic processing following left hemisphere stroke. For BWA, reduced reading accuracy was further expected to reflect challenges associated with language non-selective access and competition resolution within an integrated bilingual lexicon. Across both aphasia groups, the overall distribution of acquired dyslexia subtypes was expected to align with prior literature in which phonological dyslexia is the most frequently observed profile among bilingual (Goral, 2019; Kuzmina et al., 2019) and monolingual individuals (Beeson et al., 2022; Brookshire et al., 2014; Luzzatti et al., 2006; Madden et al., 2018).

As noted in Chapter 3.2, much of the bilingual aphasia literature has described acquired reading disorders in terms of differential or parallel impairment across languages, classifications that are defined relative to each individual's pre- and post-morbid language abilities and are most informative in single-case or small case-series designs. In the present study, cross-language reading patterns are examined at both the group and individual levels using direct comparisons to the BNC; accordingly, the terms *parallel* and *differential* are not used as they imply change relative to premorbid ability. Instead, individual-level patterns are characterized in terms of concordant (i.e., same) or discordant (i.e., different) dyslexia profiles across English and Spanish. Prior bilingual aphasia studies that reported dyslexia subtypes in both languages have overwhelmingly documented the same diagnostic

profile between the two languages (Goral, 2018), with only one report of differing diagnoses across languages (Karanth, 2002). Therefore, the BWA in this study were expected to show mostly concordant patterns of phonological dyslexia in both languages.

6.2.2. Aim 1.2.

To what extent do non-orthographic semantic and phonological abilities predict reading impairment in BWA?

Aim 1.2 examined whether individual differences in central semantic and phonological abilities predict reading performance in BWA, as predicted by the Primary Systems Hypothesis and its implementation in the triangle model of reading (Patterson & Lambon Ralph, 1999; Crisp & Lambon Ralph, 2006) and the BIAA model. Within this framework, reading impairments are expected to arise from damage to modality-independent semantic and phonological systems, or the mappings between them, that jointly support spoken and written language. Semantic abilities are therefore expected to support real word reading and reading comprehension, whereas phonological abilities are expected to play a stronger role in oral reading of phonologically demanding items such as nonwords.

This aim focused specifically on BWA rather than including parallel models in MWA because the relevant spoken–written language relationships in MWA have already been well characterized. Madden et al. (2018), for example, demonstrated that semantic abilities robustly predict real word reading and reading comprehension, whereas phonological abilities selectively predict performance on nonword reading and sentence-level comprehension. That study provided strong evidence that orthographic processing in

aphasia is constrained by the integrity of underlying semantic and phonological systems rather than by damage to orthography-specific mechanisms alone. Aim 1.2 therefore builds directly on this work by asking whether the same system-level relationships govern reading performance in bilingual aphasia, and crucially, whether they do so across both languages.

Hypotheses. Based on prior findings in MWA (Madden et al., 2018) and predictions of the Primary Systems Hypothesis, non-orthographic semantic abilities were expected to predict real word oral reading and reading comprehension performance in BWA, whereas non-orthographic phonological abilities were expected to more strongly predict nonword oral reading. Critically, these relationships were expected to emerge in *both* English and Spanish. Evidence that semantic and phonological abilities predict reading performance similarly across languages would indicate that reading impairments in BWA reflect disruption to shared, modality-independent systems rather than damage to language-specific orthographic representations. Such a pattern would further support accounts of bilingual language organization that posit an integrated, language non-selective lexical system that continues to operate post-stroke.

6.2.3. Aim 1.3.

To what extent is reading accuracy modulated by phonological and orthographic overlap between English and Spanish in BWA?

This aim examines bilingual-specific influence on word recognition and oral reading that arise from cross-language activation within an integrated lexical system. As described in Chapter 5, bilingual word recognition involves the simultaneous activation of lexical candidates from both languages, generating cross-language cohorts that must be

resolved prior to final selection. Evidence for this process comes from well-documented effects such as cognate facilitation and homograph interference (Beauvillain & Grainger, 1987; de Groot et al., 2000; Dijkstra et al., 1999; 2000; Dijkstra et al., 2010; Voga & Grainger, 2007). When words share semantic and orthographic representations (i.e., cognates), word reading is faster and/or more accurate and when those representations diverge (i.e., homographs), word reading is slower and/or less accurate. Together, these effects underscore how converging or competing representations across languages shape reading behavior in bilinguals.

Hypotheses. In BWA, greater phonological and/or orthographic overlap between Spanish and English was expected to facilitate word reading accuracy. Specifically, words that shared more letters and/or sounds across languages should be read more accurately than words with minimal cross-language overlap. In addition, measures indexing cohort size such as phonological or orthographic neighborhood density within and across languages were expected to predict reading accuracy. For example, van Heuven et al. (1998) and Grainger and Dijkstra (1992) both revealed that more orthographic neighbors (i.e., greater orthographic neighborhood density) within and between languages had a positive effect on word recognition.

6.3. Aim 2: To Investigate Real-Time Reading Comprehension Using Eye Tracking

Using eye tracking during reading, Aim 2 examined whether reading comprehension deficits in MWA and BWA (relative to respective controls) were due to delayed lexical access (at the single word level) and/or deficits in lexical integration and whether sentence-level impairments were related to lexical features known to influence

healthy bilingual language processing such as cognates and homographs (in the BWA only). In general, the BWA were expected to demonstrate *exaggerated effects* of cognate facilitation and homograph interference while reading and crucially, these differences would be *delayed* and *persist longer* than for the BNC across measures of eye tracking.

6.3.1. Aim 2.1.

To what extent do comprehension accuracy and global reading time differences emerge as a function of reading behavior differences among groups?

Hypotheses. Overall, BWA and MWA were expected to answer fewer comprehension questions accurately and demonstrate exaggerated total reading times when compared to BNC and MNC. These hypotheses are consistent with evidence from Chapter 4 that revealed inflated total reading times and lower accuracy on comprehension questions between PWA and healthy controls in eye tracking during reading studies (e.g., DeDe, 2017; DeDe & Kelleher, 2021).

6.3.2. Aim 2.2.

How do monolingual and bilingual adults process semantic constraint during online reading and how does aphasia affect this processing?

Hypotheses. For all groups, high semantic constraint sentences were expected to facilitate online reading relative to low constraint sentences, resulting in faster reading times overall. For neurologically healthy bilingual and monolingual controls, sensitivity to semantic constraint was expected to emerge early in the time course of sentence processing and be evident across eye-tracking measures that index early-stage processing. Because

control participants were expected to process sentences efficiently, the facilitative effects of high semantic constraint were hypothesized to be absent in late-stage measures.

Adults with aphasia were also expected to show sensitivity to the semantic constraint manipulation. However, relative to controls, semantic constraint effects in aphasia were predicted to be delayed and exaggerated over the time course of processing. Consistent with prior eye-tracking studies in aphasia (e.g., Huck et al., 2017a; Knilans & DeDe, 2015), interactions between sentence-level context and reading behavior were expected to emerge later and persist across successive stages of processing. These prolonged effects were anticipated to be most evident in eye-tracking measures that index later rereading and integrative processes, reflecting slower or less efficient use of contextual information during online reading.

6.3.3. Aim 2.3.

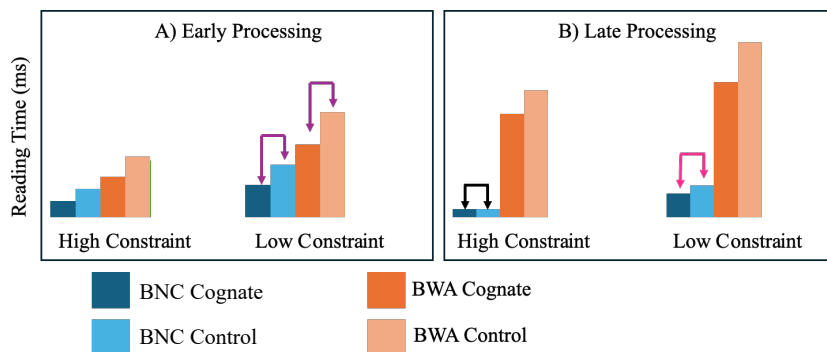
To what extent do the bilingual groups show cognate facilitation and homograph interference effects in online sentence processing?

Cognate Hypotheses. Consistent with previous studies (Libben & Titone, 2009; Schwartz & Kroll, 2006), the BNC were anticipated to demonstrate significantly faster reading times for cognates vs. control words and this difference would have been greater (i.e., cognates even faster) in high vs. low constraint sentences (Figure 6.2).

Because the BNC were expected to process the sentences quickly, eye tracking measures that indexed the earliest stages of lexical processing were expected to capture cognate facilitation in both high and low constraint sentences (blue comparisons in Figure 6.2A). In later stages of lexical processing, high constraint would exert a top-down

influence on cognate effects and therefore, facilitation would only be observed in low constraint sentences where processing may still be supported by lexical effects (pink vs. black comparisons in Figure 6.2B). Although the cognate facilitation patterns were expected to be similar for the BWA (compared to the BNC), three distinct findings should have emerged. First, the cognate facilitation effects were expected to be *exaggerated* (i.e., greater difference magnitude in reading cognates vs. control words) when compared to BNC (for example, purple comparisons in Figure 6.2A). Previous studies have reported larger lexical effects such as frequency and word class for PWA than monolingual controls during eye-tracking-while-reading (DeDe, 2017; DeDe & Kelleher, 2021; Johnson & Rayner, 2007). Second, the predicted interaction between cognate facilitation and semantic constraint was expected to be *delayed* for the BWA (e.g., consistent with Huck et al., 2017a) and third, the effects would *persist* (e.g., consistent with Knilans & DeDe, 2015), especially in eye tracking measures that index later stages of processing when the discrepancy in reading times between BWA and BNC would be most exaggerated (orange bars vs. blue bars in Figure 6.2B).

Figure 6.2 Predicted Cognate Effects



Caption. Constraint conditions are shown along the x axis and reading time is shown on the y. Cognate and control reading times are relative to demonstrate hypothesized effects

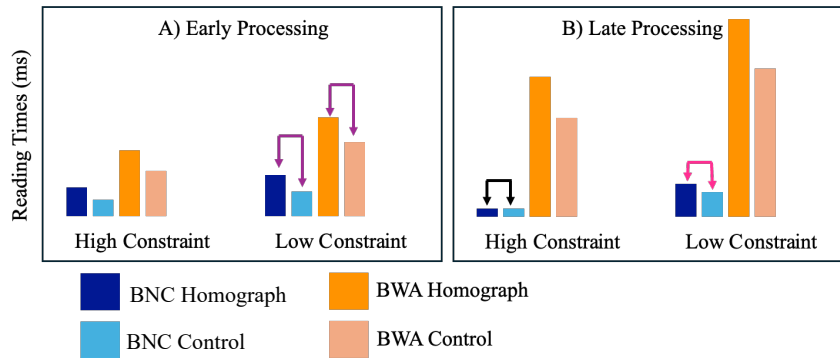
between groups.

Homograph Hypotheses. The BNC were expected to demonstrate significantly slower reading times for homographs vs. control words and this difference would have been greater in low vs. high constraint sentences because resolving competition between two meanings would occur more slowly when sentence context is less clear (Figure 6.3).

Although the BNC were expected to show homograph interference effects in both high and low constraint conditions during the first pass through the sentence (i.e., early processing), these effects were anticipated to diverge in later stages of processing. In successive passes through the sentence, high constraint should diminish the homograph effects (i.e., context attenuates the processing costs of homographs) and therefore, interference would be observed in low constraint sentences (pink vs. black comparisons in Figure 6.3B) where processing is more difficult due to the compounded effects of these lexical and semantic factors. As in the cognate predictions, the BWA were expected to show similar patterns of homograph interference across the constraint sentences. However, the interference effects were expected to be *exaggerated* (i.e., greater difference magnitude in reading homographs vs. control words) than those observed in the BNC (purple comparisons in Figure 6.3A) consistent with studies like DeDe, 2017. Reading times were expected to be slowest for BWA when reading homograph words in low-constraint sentences where *slowed* lexical processing would be further taxed when i) resolving dual meanings of the target word and ii) semantic context is less informative about sentence content. As in the cognate predictions, interactions between homograph interference and semantic constraint were hypothesized to *be delayed* for the BWA (e.g., consistent with

Huck et al., 2017a) and would *persist* over the time course of sentence processing (e.g., consistent with Knilans & DeDe, 2015).

Figure 6.3 Predicted Homograph Effects



Caption. Constraint conditions are shown along the x axis and reading time is shown on the y. Homograph and control reading times are relative to demonstrate hypothesized effects between groups.

7. AIM 1: CLINICAL ASSESSMENT OF ALEXIA

7.1. Method

7.1.1. Participants

Participants were 20 English-speaking monolinguals with aphasia (MWA), 16 English-speaking monolingual neurological controls (MNC), 11 Spanish-English bilinguals with aphasia (BWA), and 8 bilingual neurological controls (BNC). All participants were 18-85 years old and demonstrated adequate hearing and normal or corrected-to-normal vision to complete study procedures. Participants were excluded if they reported i) a neurological illness (other than stroke in the MWA and BWA) or neuropsychiatric disorder (e.g., schizophrenia) that could interfere with study performance; or ii) a learning disability, especially developmental dyslexia that could have caused reading difficulties across the lifespan. Before enrolling in the study, participants provided written informed consent in accordance with the Boston University Charles River Campus Institutional Review Board (Reference Number: 3309E).

The MWA group consisted of 20 individuals (8 female, 12 male) with a mean age of 63 years (SD = 7.6; range: 50–77) and an average of 13 years of education (SD = 2; range: 13–22). All participants were in the chronic stage of recovery (>6 months post-onset), with a mean time post-onset of 113.5 months (SD = 114; range: 22–565). Western Aphasia Battery–Revised Aphasia Quotient (WAB-R AQ; Kertesz, 2007) scores indicated mild to moderate aphasia severity (mean = 90.4, SD = 8.8, range: 63.1-100). According to WAB-R diagnostic criteria, 9 participants were classified as having anomic aphasia and 2

as having conduction aphasia; the remaining individuals fell within the “no aphasia by WAB-R” (NABW) range due to very mild impairment. See Table 7.1 for individual demographic characteristics for the MWA group.

The MNC group consisted of 16 individuals (11 female, 5 male) who had a mean age of 61.8 years ($SD = 8.7$, range: 47-73) and an average of 18.5 years of education ($SD = 3.2$, range: 14-27). The MNC group was matched to the MWA group on age and education. Given the small and unequal sample sizes, Mann-Whitney U tests were used to assess demographic differences. Results indicated no significant differences in age ($U = 166.5, p = .85$) or education ($U = 115.0, p = .14$). As part of the inclusion criteria, all MNC demonstrated intact cognition by scoring within normal limits on the Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005). See Table 7.2 for individual demographic characteristics for the MNC group.

The BWA group consisted of 11 individuals (5 female, 6 male) who had a mean age of 51.2 years ($SD = 14.9$, range: 27-75) and an average of 16.4 years of education ($SD = 3.6$, range: 12-22). All BWA were in the chronic stage of recovery and had a mean time post-onset of 112.9 months ($SD = 65.3$, range: 41-237). 8 individuals reported Spanish as their L1 and the mean age of second language acquisition was 11.3 years ($SD = 7.7$, range: 1-21 years). WAB-R AQ scores revealed moderate aphasia severity in English (mean = 79.9, $SD = 20.0$, range: 42.9-98) and comparable severity in Spanish (Kertesz et al., 1990;) mean = 74.2, $SD = 17.9$, range: 40.1-95.4). Based on WAB-R criteria, aphasia classifications were: 3 anomic, 2 Broca's, 1 conduction, and 5 NABW in English and 6 anomic, 2 Broca's, 2 conduction, and 1 NABW in Spanish. See Table 7.3 for individual

demographic characteristics for the BWA group.

The BNC group consisted of 8 individuals (5 females, 3 males) who had a mean age of 38.2 years (SD = 16.1, range: 24-72) and an average of 17.6 years of education (SD = 3.37, range: 12-22). The BNC group was matched to the BWA group on age and education. Given the small and unequal sample sizes, Mann–Whitney U tests were used to assess demographic differences. Results indicated no significant differences in age ($U = 67.00, p = .063$) or education ($U = 36.00, p = .531$) between the groups. As part of the inclusion criteria, all BNC participants demonstrated intact cognition by scoring within normal limits on the MoCA. See Table 7.4 for individual characteristics for the BNC group.

Table 7.1 MWA Demographic Characteristics

ID	Sex	Hand	Age	Edu	MPO	Race	Ethnicity	WAB AQ	WAB-R Classification
MWA01	F	R	70	22	89	White	Non-Hispanic	97.7	NABW
MWA02	M	L	71	17	101	White	Non-Hispanic	91.2	Anomic
MWA03	F	L	53	20	47	White	Non-Hispanic	92.2	Anomic
MWA04	F	R	63	16	67	White	Non-Hispanic	97.7	NABW
MWA05	F	R	62	18	180	White	Non-Hispanic	96.4	NABW
MWA06	M	R	71	16	85	White	Non-Hispanic	96.3	NABW
MWA07	F	R	54	19	22	White	Non-Hispanic	100	NABW
MWA08	M	R	51	16	56	White	Non-Hispanic	93.8	NABW
MWA09	M	R	67	20	94	White	Non-Hispanic	85.2	Anomic
						Black or African			
MWA10	M	R	68	13	72	American	Non-Hispanic	88.6	Anomic
MWA11	F	L	50	16	199	White	Non-Hispanic	86.9	Anomic
MWA12	M	R	77	15	63	White	Non-Hispanic	73.5	Conduction
						Black or African			
MWA13	F	R	61	16	105	American	Non-Hispanic	86.2	Anomic
MWA14	M	R	73	18	60	White	Non-Hispanic	92.1	Anomic
MWA15	M	R	61	16	565	White	Non-Hispanic	91.3	Anomic
MWA16	F	L	62	16	134	White	Non-Hispanic	96.1	NABW
						Black or African			
MWA17	M	R	66	16	44	American	Non-Hispanic	88.7	Anomic
MWA18	M	R	66	16	87	White	Non-Hispanic	98	NABW
MWA19	M	R	60	16	81	White	Non-Hispanic	63.1	Conduction
MWA20	M	R	54	19	119	White	Non-Hispanic	94.6	NABW
Mean			63	17.0	113.5			90.4	
SD			7.6	2.0	114.7			8.8	

Note. *Edu* = Education (yrs); *MPO* = Months post-onset; *NABW* = Not Aphasic by WAB

Table 7.2 MNC Demographic Characteristics

ID	Sex	Hand	Age	Edu	Race	Ethnicity	MoCA
MNC01	M	R	49	18	White	Non-Hispanic	30
MNC02	M	R	62	16	White	Non-Hispanic	30
MNC03	F	R	66	16	White	Non-Hispanic	28
MNC04	F	R	63	22	White	Non-Hispanic	30
MNC05	F	R	68	17	White	Non-Hispanic	30
MNC06	F	R	68	23	White	Non-Hispanic	28
MNC07	F	R	58	18	White	Non-Hispanic	30
MNC08	M	L	70	18	NR	NR	30
MNC09	M	R	71	27	White	Non-Hispanic	27
MNC10	F	R	70	16	White	Non-Hispanic	28
MNC11	F	R	62	16	White	Non-Hispanic	28
MNC12	M	R	51	19	White	Non-Hispanic	29
MNC13	F	R	73	20	White	Non-Hispanic	26
MNC14	F	R	48	14	White	Non-Hispanic	26
MNC15	F	R	64	18	White	Non-Hispanic	30
MNC16	F	R	47	18	White	Non-Hispanic	29
Mean			61.8	18.5			28.6
SD			8.7	3.2			1.4

Note. *Edu* = Education (yrs); *MoCA* = Montreal Cognitive Assessment (/30); *NR* = No Response

Table 7.3 BWA Demographic Characteristics

ID	Sex	Hand	Age	Edu	MPO	Race	Ethnicity	L1	AoA	WAB AQ - ENG	WAB-R Classification - ENG	WAB AQ - SPN	WAB-R Classification -SPN
BWA01	M	R	52	16	237	White	Hispanic	Spanish	6	94	NABW	85.4	Anomic
BWA02	M	L	50	22	43	White	Hispanic	Spanish	6	95.4	NABW	95.4	NABW
BWA03	M	L	65	22	165	White	Non-Hispanic	Hebrew*	16	94.2	NABW	59.7	Conduction
BWA04	F	R	32	13	191	White	Hispanic	Spanish	5	76.6	Anomic	79.5	Anomic
BWA05	M	R	45	13	112	White	Hispanic	Spanish	21	42.9	Broca's	47.8	Broca's
BWA06	M	R	75	14	54	White	Hispanic	Spanish	8	83.5	Anomic	81.4	Anomic
BWA07	F	R	38	17	41	White	Non-Hispanic	English	19	98	NABW	87.7	Anomic
BWA08	M	R	65	19	52	White	Non-Hispanic	English	21	96	NABW	82.5	Anomic
BWA09	F	R	61	14	119	White	Hispanic	Spanish	1	87.5	Anomic	68.7	Conduction
BWA10	F	R	54	19	138	White	Hispanic	Spanish	18	46.2	Broca's	89	Anomic
BWA11	F	L	27	12	90	White	Hispanic	Spanish	3	65.6	Conduction	40.1	Broca's
Mean			51.2	16.4	112.9				11.3	79.9		74.2	
SD			14.9	3.6	65.3				7.7	20.0		17.9	

Note. *Edu* = Education (yrs); *MPO* = Months post-onset; *AoA* = L2 Age of Acquisition; *NABW* = Not Aphasic by WAB

Table 7.4 BNC Demographic Characteristics

ID	Sex	Hand	Age	Edu	Race	Ethnicity	L1	AoA	MoCA
BNC01	F	R	24	16	White	Non-Hispanic	English	13	30
BNC02	M	R	29	22	White	Non-Hispanic	Spanish	3	27
BNC03	F	R	24	16	White	Non-Hispanic	English	6	28
BNC04	M	R	72	18	White	Hispanic	Spanish	30	29
BNC05	F	R	29	22	White	Hispanic	Spanish	3	28
BNC06	M	R	48	16	White	Non-Hispanic	Spanish	15	30
BNC07	F	R	43	12	Asian	Hispanic	Spanish	18	26
BNC08	F	R	37	19	White	Non-Hispanic	English	7	30
Mean			38.2	17.6				11.8	28.5
SD			16.1	3.3				9.2	1.5

Note. *Edu* = Education (yrs); *AoA* = L2 Age of Acquisition; *MoCA* = Montreal Cognitive Assessment score (/30)

7.1.2. Behavioral Assessment

All behavioral assessments were constructed by adapting and combining subtests from established standardized batteries, including the Psycholinguistic Assessment of Language Processing in Aphasia (Kay et al., 1992) and its Spanish translation, the Evaluación del Procesamiento Lingüístico para la Afasia (Kay et al., 1995). Stimuli for the reading and language tasks followed the theoretical structure and psycholinguistic principles of these assessments to enable cross-linguistic comparisons between English and Spanish. These adaptations ensured parallel assessment across languages, controlled manipulation of lexical, phonological, and semantic variables, and appropriate representation of features that differed across orthographic systems (for example, lexical stress in Spanish or irregular spelling–sound correspondences in English). See Table 7.5 for the full list of constructed assessments.

7.1.2.1. Assessment of reading background

All participant groups completed a literacy experience questionnaire to assess their current reading habits, abilities, and attitudes. The questionnaire was designed to separate different dimensions of reading experience; for instance, an individual may report strong reading ability yet choose to read infrequently because they derive little enjoyment from it. Participants with aphasia provided ratings for both pre-morbid reading experience, defined as approximately six months before their stroke, and post-onset reading experience. Bilingual participants provided these ratings separately for English and Spanish. All responses were given on a 1–10 Likert scale, where 1 indicated the least engaged or least proficient scenario, such as infrequent reading, low ability, or low motivation. The

questionnaire was administered in English through a clinical interview, and members of the study team used Spanish as needed to support completion of the questionnaire.

7.1.2.2. Assessment of reading ability

To evaluate individual reading abilities and potential impairment across English and Spanish, all participants completed a battery of oral reading and silent reading comprehension tasks. Since the two languages differed substantially in orthographic transparency and in the criteria used to diagnose subtypes of acquired dyslexia, some tasks were administered in only one language. In English, oral reading tasks included a list of 30 regular and exception words (for example, *cat* and *yacht*) that examined the strength of spelling–sound representations in American English. Participants also read 80 words that differed by part of speech, divided evenly into nouns, verbs, adjectives, and functor words such as prepositions and conjunctions. Nonword reading was assessed using 100 phonotactically legal nonwords, of which 53 were nonhomophonic items like *gaffic* that should be decoded using grapheme–phoneme correspondence rules. The remaining 47 nonword items were pseudohomophones that closely resemble real English words and should be pronounced identically such as *thease*. Participants also read 36 sentences that varied in syntactic structure, including active and passive constructions, as well as reversible and nonreversible semantic structures, as shown by sentences such as ‘The man is kicking the horse’ or ‘The horse was kicked by the man’.

In Spanish, distinctions based on word regularity are not meaningful due to the language’s transparent orthography. For this reason, the English list of regular and exception words was replaced with a set of 60 words that varied in lexical frequency and

letter length. Participants also completed a list of 40 words with deleted written stress marks and were asked to read the words aloud to assess visual word representations and stress assignment. As discussed in Chapter 2, lexical stress errors in Spanish oral reading may be a diagnostic indicator of surface dyslexia (Ferrerres et al., 2005; Ferreres et al., 2012). All remaining oral reading tasks in Spanish were administered in the same manner as in English.

The silent reading comprehension battery consisted of 40 word–picture matching and 40 sentence–picture matching items in which participants read a word or sentence silently and selected the picture that best matched its meaning from a field of five or three options, respectively. Participants also completed two lexical decision tasks. In the first, they read 60 real words and 60 nonhomophonic nonwords and were instructed to circle only the real words. In the second, they read 30 real words and 30 pseudohomophones and again circled only the real words. Spanish versions of all four tasks were administered using the same procedures.

Across testing sessions, the order of oral reading and reading comprehension tasks was counterbalanced. Within each modality, the order of individual subtests was pseudorandomized. For oral reading, real words were always administered before nonwords, although the specific real-word and nonword lists could be presented in any order. For reading comprehension, either the lexical decision tasks or the picture-matching tasks could be administered first. For the BNC and BWA groups, testing in English and Spanish was conducted one language at a time to minimize cross-language interference during behavioral assessment.

7.1.2.3. Assessment of other language modalities

In addition to the oral reading and reading comprehension assessments, participants completed non-orthographic semantic and phonological processing tasks to isolate and evaluate other aspects of linguistic functioning. The semantic tasks consisted of spoken word– and sentence–picture matching, which paralleled the reading comprehension versions. A member of the study team read a word or sentence aloud, and participants selected the picture that best matched its meaning. The phonological processing battery included four tasks targeting different components of auditory–phonological analysis. The first was an auditory lexical decision task composed of 40 real words and 40 nonhomophonic nonwords, to which participants responded “yes” for real words and “no” for nonwords. The second task was oral repetition of 40 real words and 40 nonhomophonic nonwords. The third was a sound deletion task in which participants repeated 25 real words and then repeated each a second time with a syllable or phoneme removed (for example, say “rainbow,” then say it again without “rain”). The final task was rhyme judgment, in which participants heard 60 word pairs in English, or 40 in Spanish, and indicated whether the pairs rhymed. Spanish versions of all semantic and phonological tasks were administered using the same procedures as in English.

Table 7.5 Assessment Battery & Task Administration by Group

Assessment/Task	N. Items	Domain	Admin. Lang	Groups Completed
Oral Reading: Word Regularity	60 (30/30)	Oral Reading	Both	BWA, BNC, MWA, MNC
Oral Reading: Grammatical Class	80 (20/20/20/20)	Oral Reading	Both	BWA, BNC, MWA, MNC
Oral Reading: Nonhom. Nonwords	53	Oral Reading	Both	BWA, BNC, MWA, MNC
Oral Reading: Pseudohomophones	47	Oral Reading	Both	BWA, BNC, MWA, MNC
Oral Reading: Spanish Real Words	60	Oral Reading	Spanish	BWA, BNC
Oral Reading: Spanish Lexical Stress	40	Oral Reading	Spanish	BWA, BNC
Written-Word Pic Matching	40	Reading Comp.	Both	BWA, BNC, MWA, MNC
Written-Sent Pic Matching	40	Reading Comp.	Both	BWA, BNC, MWA, MNC
Visual Lexical Decision	120 (60/60)	Reading Comp.	Both	BWA, BNC, MWA, MNC
Pseudohomophone Decision	60 (30/30)	Reading Comp.	Both	BWA, BNC, MWA, MNC
Spoken-Word Pic Matching	40	Semantics	Both	BWA, BNC
Spoken-Sent Pic Matching	40	Semantics	Both	BWA, BNC
Auditory Lexical Decision	80 (40/40)	Phonology	Both	BWA, BNC
Real word/Nonword Repetition	80 (40/40)	Phonology	Both	BWA, BNC
Sound Deletion Task	25	Phonology	Both	BWA, BNC
Rhyme Judgment	60 (S: 40)	Phonology	Both	BWA, BNC

Note. MWA and MNC will complete tasks in English only. *Domain* denotes the broader speech/language category for each task. *Admin. Language* conveys the language in which a task will be administered; *Groups Completed* = which study groups completed the given tasks. Generally, the BNC completed the same tasks as the BWA since there were no norms available from any of the tests for Spanish-English bilinguals specifically. *N. Items* = Number of items in format: total (subdivided). Oral Reading and Reading Comprehension items are only used as dependent or outcome measures across Aims 1.1-1.3 whereas semantic and phonology scores were only used as predictors.

7.1.3. Scoring and Coding

All tasks were scored for item-level accuracy. Across tasks, a response was coded as correct only when the produced or selected item matched the target. Missing responses,

unintelligible productions, and self-corrections that did not ultimately yield the target were coded as incorrect. All reading assessments were untimed and individual participants were instructed that they could rephrase or change a response. Several individuals with aphasia required additional processing time to formulate responses, especially on the oral reading tasks, and therefore no penalties in accuracy occurred for timing-related differences among participants. If a participant rephrased or retried a response, only the final response was scored for accuracy. Study clinicians encouraged individuals to attempt each reading item; participants completed each item across subtests unless they requested to discontinue testing due to perceived difficulty. These accuracy scores were used to construct overall performance measures for each task in English and Spanish and served as the primary dependent variables for the statistical analyses.

For real-word oral reading specifically, incorrect responses were further classified into detailed error categories to identify profiles of acquired dyslexia and to support the analyses in Aim 1.1. Errors were categorized using a standardized coding scheme that distinguished phonological errors, semantic paralexias, morphological or derivational errors, regularization errors, visual errors, and omissions. When relevant, responses were also coded for lexical stress errors in Spanish, given their diagnostic significance for surface dyslexia. Error codes for semantic paralexias and lexical stress errors were aggregated and analyzed as part of Aim 1.1 for the aphasia groups only.

7.1.4. Statistical Analyses and Rationale

Across the research questions in Aim 1, a mixed-effects modeling framework was implemented. This approach was selected because the behavioral assessment data

consisted of trial-level accuracy from multiple tasks, with repeated observations nested within participants and stimuli (Baayen et al., 2008; Jaeger, 2008). Generalized linear mixed-effects models (GLMMs) were therefore used to estimate the likelihood of a correct response to each item, and random effects for participant and item were included whenever possible to capture individual differences in bilingual language background, baseline linguistic ability, and item-specific variability. All models were fit using a logit link function in the lme4 package in R (Bates et al., 2015).

7.1.4.1 Aim 1.1

Aim 1.1 examined reading impairment in individuals with aphasia by modeling overall reading performance relative to neurological controls and by comparing the distribution of acquired dyslexia subtypes across bilingual and monolingual aphasia groups.

The first component of the analysis evaluated impairment across oral reading and reading comprehension by testing whether accuracy differed between adults with aphasia and neurological controls using generalized linear mixed-effects models. For the bilingual groups, an overall model was fit to all oral reading and reading comprehension items (see Table 7.5). Fixed effects included group (BWA vs. BNC), test language (English vs Spanish), domain (oral reading vs reading comprehension; sum-coded), standardized age, standardized education, standardized premorbid reading ability, and interactions among group, test language, and domain. Random intercepts for items and participants were included to account for variability in item difficulty and individual reading ability. Estimated marginal means and confidence intervals were derived using the emmeans

package to summarize predicted accuracy across groups, languages, and domains at standardized values of age, education, and premorbid reading ability.

An analogous mixed-effects model was fit for the monolingual participants. This model used the same overall structure and covariates as in the bilingual model but it did not include a language term since the monolinguals completed assessments in English only or a premorbid reading ability term since all participants learned to read at a high-level before their brain injury (i.e., they learned to read in one language only). Therefore the fixed interaction included only group x domain.

The second component of Aim 1.1 examined the linguistic sources of impairment by classifying acquired dyslexia subtypes in English and Spanish. These analyses were grounded in established psycholinguistic markers of acquired dyslexia and evaluated lexicality effects, regularity effects (English only since regularity effects do not exist in Spanish), semantic error patterns, lexical stress errors (Spanish only), and phonologically plausible errors on exception words. The objective was to determine whether participants showed patterns consistent with phonological, surface, deep, or unimpaired profiles within each language, and to compare these patterns across groups and across languages.

Following procedures outlined in Beeson et al. (2022), lexicality effects were computed as the accuracy difference between real words and nonwords, and regularity effects were computed as the difference between regular and exception word accuracy. Each BWA and MWA's lexicality and regularity effects were compared to their respective neurological control performance using single-case Crawford–Howell (1998) tests. Incorrect real-word responses were coded for error subtype, including semantic

substitutions, phonologically plausible errors, and lexical stress errors (Spanish only) for the BWA and MWA participants only. A minimum threshold of five real-word errors was required for semantic or stress patterns to be considered interpretable, and proportional error rates of at least 10 percent were used to identify meaningful semantic or stress effects.

Subtype classification proceeded independently for each language. In English, phonological dyslexia was defined by a significant lexicality effect—as defined by $p < .05$ on the Crawford-Howell test—in the absence of a detectable semantic error rate. Surface dyslexia required a significant regularity effect ($p < .05$) accompanied by phonologically plausible errors and no lexicality effect. Deep dyslexia required both a significant lexicality effect and a detectable semantic error rate (\geq five semantic errors and ≥ 10 percent semantic errors overall). Participants who did not meet criteria for any profile were classified as unimpaired. In Spanish, phonological dyslexia was defined by a significant lexicality effect without semantic or stress effects, surface dyslexia was defined by a systematic lexical stress error pattern (\geq five stress errors and ≥ 10 percent stress errors overall), and deep dyslexia required co-occurrence of a significant lexicality effect and a semantic error pattern. Any BWA and MWA participants who did not meet criteria for any subtype were classified as unimpaired. Subtypes were summarized for both aphasia groups and, for the BWA, across languages to evaluate cross-language concordance.

7.1.4.2 Aim 1.2

Aim 1.2 examined whether non-orthographic semantic and phonological processing could be used to predict reading performance across oral reading and reading comprehension in English and Spanish for the BWA.

Before statistical modeling, semantic and phonological composite scores were calculated for each BWA relative to BNC. For each individual subtest that was used in the two composites, z-scores were computed for each BWA relative to the other members of the group. Z-scores were computed separately within each language and then the subtests within each domain (i.e., semantics or phonology) were averaged together to form the composite. Greater composite scores, therefore, reflected better semantic and/or phonological processing relative to the entire BWA group. The semantic composites were defined as the mean of two z-scores from the auditory word-picture-matching and sentence-picture-matching subtests. The phonological composites were computed similarly and were defined as the mean of the four z-scores from the auditory lexical decision, oral repetition, sound deletion, and rhyme judgment tasks in each language.

The semantic and phonological composites were entered into a series of mixed-effects models along with covariates for age and education, centered at the mean, and test language to allow separate predictions for English and Spanish. These fixed effects, along with random intercepts for participant and item, were included in a series of generalized linear mixed-effects models for oral reading and reading comprehension. Oral reading was examined using three models defined by the dependent variables: (i) accuracy on real word oral reading, (ii) accuracy on nonword oral reading, and (iii) overall accuracy across all oral reading items. Reading comprehension was examined using a corresponding set of models: (i) accuracy on single-word comprehension, (ii) accuracy on sentence comprehension, and (iii) overall comprehension accuracy. Because these analyses tested distinct, a priori hypotheses about the role of semantic and phonological systems under

different reading demands and across domains, no correction for multiple comparisons was applied.

7.1.4.3. Aim 1.3

Aim 1.3 examined how cross-linguistic phonological and orthographic overlap influenced single-word reading performance in the BWA group. For each word, we computed phonological similarity and orthographic similarity metrics between the Spanish stimulus and its English translation equivalent (and vice versa) by examining (mis)matches between sounds and letters, respectively. For the computation of cross-language phonological similarity, phonological forms were first converted to International Phonetic Alphabet (IPA) strings and tokenized into phoneme-level units using a custom procedure designed to preserve linguistically meaningful distinctions while allowing graded similarity. Prior to tokenization, primary and secondary stress markers were removed, and all affricates and diphthongs were normalized to single symbols to prevent treatment as multi-segment sequences. Phonological distance between translation equivalents was then calculated using a weighted Levenshtein alignment over the decomposed phoneme token vectors; insertion and deletion costs were fixed at 1 and substitution costs were determined by a phoneme similarity function (Kondrak, 2003). This approach allowed phonemes that were not identical across languages to be treated as more or less similar depending on their feature composition. For example, the English word piano /pi'ænoʊ/ and its Spanish translation /pjano/ share several phonemes (e.g., /p/ and /n/) but differ in vowel quality. A strict edit-distance approach would treat the English vowel /æ/ and the Spanish vowel /a/ as maximally different, effectively penalizing this substitution as a full mismatch (Heeringa

et al., 2006). However, because /æ/ does not occur in Spanish, this difference reflects a predictable cross-language mapping rather than a complete phonological mismatch. Under the phoneme similarity metric, such substitutions were assigned a graded cost between 0 and 1 based on shared phonological features, allowing partial overlap between vowels and some consonants including, for example, Spanish intervocalic allophones and their English counterparts and differences in rhotic consonants and vowels, affricates, vowel groupings, and broad consonantal classes (e.g., dental vs. interdental sounds), to be represented in the distance calculation. The resulting phonological distance was normalized by the length of the longer string to yield a value between 0 and 1, and this value was subtracted from 1 to yield a similarity metric in which values closer to 1 indicate greater phonological similarity. Orthographic similarity was computed separately using a standard normalized Levenshtein distance over character strings (Schepens et al., 2012), with equal costs for insertions, deletions, and substitutions. Together, these procedures allowed phonological and orthographic similarity to be operationalized as continuous, gradient measures that capture both fine-grained cross-linguistic correspondences and broader structural overlap between translation equivalents.

The phonological and orthographic similarity metrics and their interaction were centered and entered into a logistic mixed effects model along with fixed effects for language (English vs. Spanish), domain (oral reading vs. reading comprehension), cross-language phonological neighborhood density, and cross-language orthographic neighborhood density. Both the similarity metrics and the neighborhood density metrics were included as separate predictors to examine effects at sublexical and lexical levels of

bilingual processing, respectively. Language and domain were treated as categorical predictors and sum coded so that model coefficients reflected deviations from the grand mean across levels. Accuracy on each real-word reading trial (correct vs. incorrect) served as the dependent variable and participants and items were included as random intercepts.

7.2. Results

7.2.1. Aim 1.1

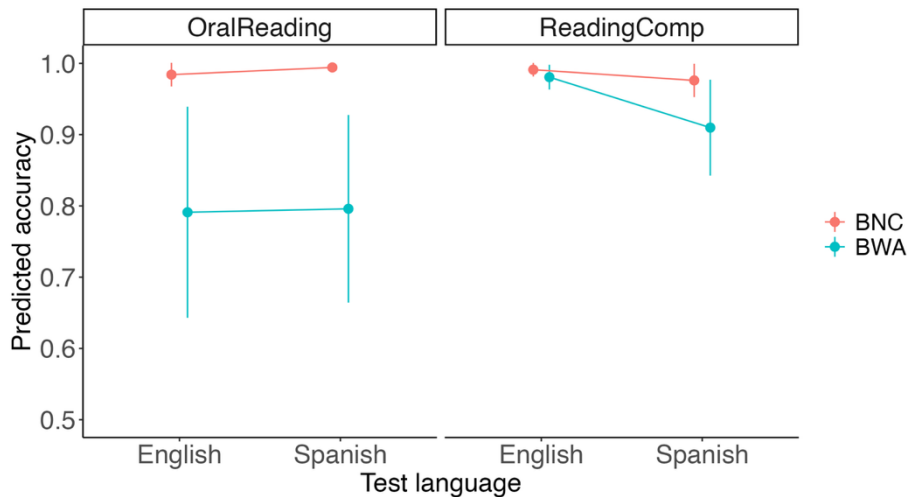
7.2.1.1. Severity and Domain-Specific Patterns of Alexia in BWA

The bilingual severity and domain-specific model evaluated how group, test language, and reading domain predicted trial-level reading accuracy, modeled as the likelihood of producing a correct response on a given reading trial. The random-effects structure indicated substantial variability across both items ($SD = 1.01$) and participants ($SD = 1.25$), and participants also varied in the magnitude of their English–Spanish differences ($SD = 0.48$).

Across languages and domains, the BWA showed a significantly lower likelihood of a correct response than the BNC ($b = -2.19$, $SE = 0.65$, $z = -3.32$, $p < .001$). There was no main effect of test language ($b = 0.00$, $SE = 0.20$, $z = -0.02$, $p = .97$), suggesting no differences in the likelihood of a correct response between English and Spanish when collapsing across groups and domains. Reading domain significantly predicted accuracy ($b = 0.21$, $SE = 0.07$, $z = 3.01$, $p < .01$), and a strong $\text{Group} \times \text{Domain}$ interaction was observed ($b = -1.10$, $SE = 0.07$, $z = -15.36$, $p < .001$), indicating that BWA accuracy was substantially lower for oral reading compared to reading comprehension. The $\text{Group} \times \text{Test}$

Language interaction was not significant ($b = 0.40$, $SE = 0.24$, $z = 1.63$, $p = .10$), nor was the three-way $\text{Group} \times \text{Test Language} \times \text{Domain}$ interaction ($b = 0.09$, $SE = 0.07$, $z = 1.33$, $p = .18$), suggesting that domain-dependent language effects did not differ reliably between the BWA and BNC. Among the covariates, education ($b = 0.65$, $SE = 0.32$, $z = 1.99$, $p = .04$) and premorbid language-specific reading ability ($b = 0.64$, $SE = 0.22$, $z = 2.88$, $p < .01$) were positively associated with greater likelihood of a correct response, whereas age was not ($b = 0.39$, $SE = 0.32$, $z = 1.21$, $p = .22$). Figure 7.1 displays the estimated marginal means from the model, illustrating the reduced accuracy for the BWA group relative to the BNC, especially in the oral reading domain as well as the absence of a consistent English–Spanish difference at the within-group level. See Table 7.6 for the full model output.

Figure 7.1 Domain-Specific Reading Accuracy for BWA vs. BNC



Caption. Points represent estimated marginal means derived from the bilingual domain model, and error bars reflect 95% confidence intervals. The figure illustrates the robust group difference in accuracy and especially reduced accuracy for oral reading in the BWA

Table 7.6 Bilingual Reading Domain Effects Model

Data	Effect	Term	Estimate	SE	Z	p-value
	Fixed	Intercept	4.42	0.48	9.18	< .001
	Fixed	Group: BWA	-2.19	0.65	-3.32	< .001
	Fixed	Test Lang (Sum-Coded)	0	0.2	-0.02	0.97
	Fixed	Domain (Sum-Coded)	0.21	0.07	3.01	< .01
All Oral	Fixed	Age (Centered)	0.39	0.32	1.21	0.22
Reading	Fixed	Education (Centered)	0.65	0.32	1.99	0.04
&	Fixed	Reading Ability (Centered)	0.64	0.22	2.88	< .01
Reading	Fixed	GroupBWA:Test Lang	0.4	0.24	1.63	0.1
Comp	Fixed	GroupBWA:Domain	-1.1	0.07	-15.36	< .001
Items	Fixed	Test Lang: Domain	-0.5	0.07	-7.08	< .001
	Fixed	GroupBWA:TestLang:Domain	0.09	0.07	1.33	0.18
	Random	Item (SD)	1.01			
	Random	Participant (SD)	1.25			
	Random	TestLang: Participant Corr	0.13			
	Random	TestLang Participant Slope	0.48			

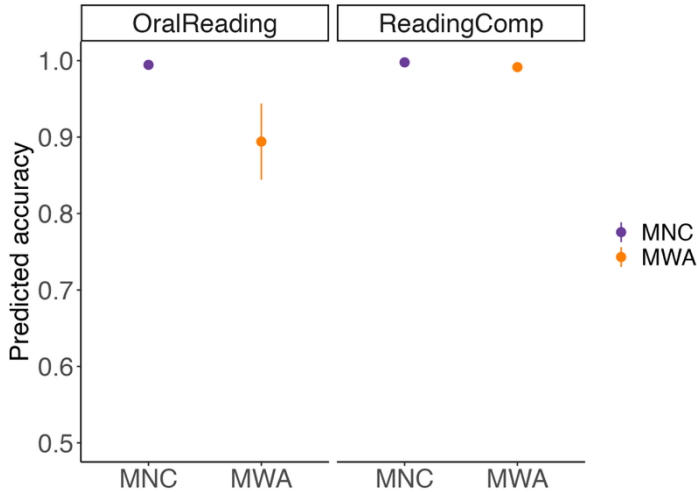
Note. *SE* = Standard Error; *Z* = z-statistic; *SD* = Standard Deviation

7.2.1.2. Severity and Domain-Specific Patterns of Alexia in MWA

Like the bilingual model, the monolingual severity and domain-specific model evaluated how group and reading domain predicted trial-level reading accuracy, modeled as the likelihood of producing a correct response on a given reading trial. The random-effects structure indicated substantial variability across both items ($SD = 1.64$) and participants ($SD = 1.06$), supporting the inclusion of random intercepts for both stimulus and participant.

Across reading domains, MWA showed a significantly reduced likelihood of a correct response across reading trials when compared to the MNC ($b = -2.20$, $SE = 0.39$, $z = -5.58$, $p < .001$). Reading domain also significantly predicted accuracy ($b = -0.45$, $SE = 0.13$, $z = -3.49$, $p < .01$), indicating a greater likelihood of a correct response for reading comprehension items when compared to oral reading. Critically, a significant $Group \times Domain$ interaction was observed ($b = -0.85$, $SE = 0.11$, $z = -7.78$, $p < .001$), indicating that MWA performance was especially reduced for oral reading items. Among covariates, neither age ($b = 0.07$, $SE = 0.18$, $z = 0.39$, $p = .69$) nor education ($b = 0.18$, $SE = 0.19$, $z = 0.92$, $p = .35$) was significantly associated with the likelihood of a correct response. Figure 7.2 illustrates the main effect of group and captures the interaction effect whereby MWA perform significantly worse on oral reading vs. reading comprehension. See Table 7.7 for the monolingual model output.

Figure 7.2 Domain-Specific Reading Accuracy for MWA vs. MNC



Caption. Points represent estimated marginal means derived from the monolingual domain model, and error bars reflect 95% confidence intervals. The figure illustrates the robust group difference in accuracy and especially reduced accuracy for oral reading in the MWA. Compared to Figure 7.1, variability across the MNC and MWA groups is reduced as evidenced by smaller or nonexistent error bars.

Table 7.7 Monolingual Reading Domain Effects Model

Data	Effect	Term	Estimate	SE	Z	p-value
	Fixed	Intercept	5.65	0.31	17.98	< .001
All Oral	Fixed	GroupMWA	-2.2	0.39	-5.57	< .001
Reading	Fixed	Domain (Sum-Coded)	-0.45	0.13	-3.49	< .001
&	Fixed	Age (Centered)	0.07	0.18	0.39	0.69
Reading	Fixed	Education (Centered)	0.18	0.19	0.92	0.35
Comp	Fixed	GroupMWA:Domain	-0.85	0.11	-7.78	< .001
Items	Random	Item (SD)	1.64			
	Random	Participant (SD)	1.06			

Note. *SE* = Standard Error; *Z* = z-statistic; *SD* = Standard Deviation

7.2.1.3. Direct BWA and MWA Reading Domain Comparisons

Given the parallel domain-dependent effects observed in bilingual and monolingual aphasia, a follow-up analysis directly compared the BWA and MWA to evaluate whether impairment across domains differed in English. A follow-up model

examined how group (bilingual vs. monolingual aphasia) and reading domain predicted trial-level reading accuracy, modeled as the likelihood of producing a correct response on a given reading trial. The random-effects structure indicated substantial variability across both items ($SD = 1.22$) and participants ($SD = 1.15$), supporting the inclusion of random intercepts for stimulus and participant.

Across domains, the BWA and MWA did not differ reliably in overall likelihood of a correct response ($b = -0.32$, $SE = 0.49$, $z = -0.65$, $p = .51$), indicating comparable global reading accuracy when collapsing across reading tasks. In contrast, reading domain exerted a strong effect on accuracy ($b = -1.07$, $SE = 0.06$, $z = -17.12$, $p < .001$), reflecting substantially lower likelihood of correct responses in oral reading relative to reading comprehension. Critically, a significant $Group \times Domain$ interaction was observed ($b = 0.21$, $SE = 0.05$, $z = 3.55$, $p < .001$), indicating that the magnitude of the domain effect differed between the BWA and MWA. Specifically, the difference in accuracy between oral reading and reading comprehension was smaller for the BWA vs. the MWA which suggests that the BWA performed more similarly across reading tasks. Among covariates, education was positively associated with the likelihood of a correct response ($b = 0.65$, $SE = 0.23$, $z = 2.77$, $p < .01$) which is likely driven by the BWA since education was not a significant predictor in the original monolingual model. Age remained nonsignificant, whereas age was not ($b = 0.17$, $SE = 0.26$, $z = 0.67$, $p = .50$). See Table 7.8 for the model output.

Table 7.8 Aphasia-only Domain Comparisons Model Output

Data	Effect	Term	Estimate	SE	Z	p-value
	Fixed	Intercept	2.69	0.29	9.18	< .001
All Oral	Fixed	GroupBWA	-0.32	0.49	-0.65	.51
Reading	Fixed	Domain (Sum-Coded)	-1.07	0.06	-17.12	< .001
&	Fixed	Age (Centered)	0.17	0.26	0.67	.50
Reading	Fixed	Education (Centered)	0.65	0.23	2.77	< .01
Comp	Fixed	GroupBWA:Domain	0.21	0.05	3.55	< .001
Items	Random	Item (SD)	1.22			
	Random	Participant (SD)	1.15			

Note. *SE* = Standard Error; *Z* = z-statistic; *SD* = Standard Deviation

7.2.1.4 Acquired Dyslexia Classification

Phonological dyslexia was diagnosed when individuals demonstrated a significant lexicality effect in the absence of elevated semantic error rates as outlined in 7.1.4.1. Surface dyslexia would have been assigned if an individual had shown a significant regularity effect in isolation, without accompanying lexicality or semantic patterns, but no participant met these criteria in English. Deep dyslexia was identified when a significant lexicality effect co-occurred with a substantial semantic error pattern, defined as producing more than five total real-word errors of which at least five were semantic. Unclassified profiles reflected cases that did not meet criteria for any specific subtype and were typically accompanied by markedly low real-word accuracy without a coherent diagnostic signature. Unimpaired profiles were assigned when individuals showed no evidence of lexicality, regularity, or semantic effects and performed near ceiling on real-word oral reading tasks. Severity of impairment (mild, moderate, global-level), based on overall real-word accuracy, is represented in Figure 7.4 alongside the overlapping diagnostic features that define unimpaired and impaired profiles.

Among BWA, English subtype assignments showed considerable variability. Five individuals (45%) were classified as having phonological dyslexia, one individual (9%) demonstrated a deep dyslexia profile, three individuals (27%) were unimpaired, and two individuals (18%) did not meet criteria for any subtype and were therefore unclassified. These results shed some light on the nature of the difference in accuracy between oral reading and reading comprehension in the first part of Aim 1.1. Given that phonological dyslexia emerged as the most consistent diagnosis among patient groups in English, these data suggest this profile was an underlying factor that explains the predominance of oral reading impairment relative to reading comprehension.

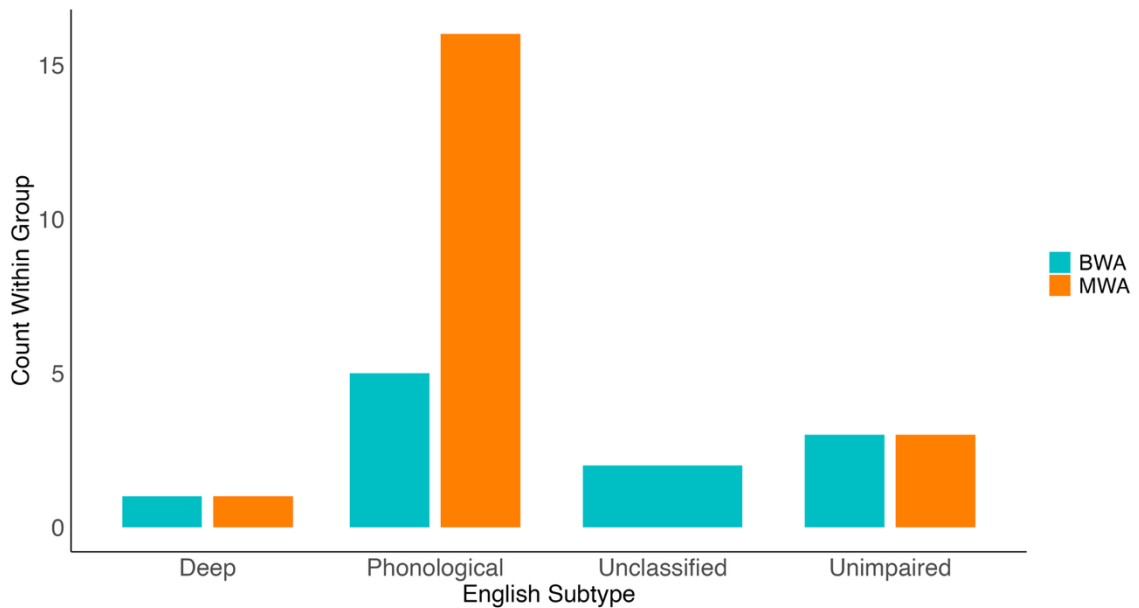
Among the MWA, sixteen individuals (80%) exhibited phonological dyslexia, three individuals (15%) were unimpaired, and one individual (5%) showed deep dyslexia. No MWA participants were classified as surface or unclassified. To evaluate whether English acquired dyslexia subtype distributions differed between the BWA and MWA, a Fisher's exact test was conducted. Subtypes were collapsed into phonological versus non-phonological (i.e., all other subtypes) due to low counts across subtypes; the test was not statistically significant (odds ratio = 0.22, $p = .10$), suggesting no reliable difference in subtype prevalence across aphasia groups. See Appendix 1 for English subtype classifications for the individual MWA and BWA participants.

Figure 7.3 Core Diagnostic Features and Severity across English subtypes



Caption. Overlapping diagnostic features and severity levels underlying English patterns of acquired dyslexia. Features represent the average magnitude of the lexicality, regularity, and semantic error rate effects that define profiles in English. For example, the phonological plot demonstrates a lexicality effect in the absence of a regularity and semantic error effect when compared to unimpaired profiles. Severity is represented as the percentage accuracy on real word reading (top point on the diamond). For example, the average phonological profile shows on-average mild severity when compared to the unimpaired group (slight reduction in real word accuracy) while the deep profile shows on average moderate severity (i.e., approx. 50% accuracy on real word reading).

Figure 7.4 Acquired Dyslexia Comparisons in English

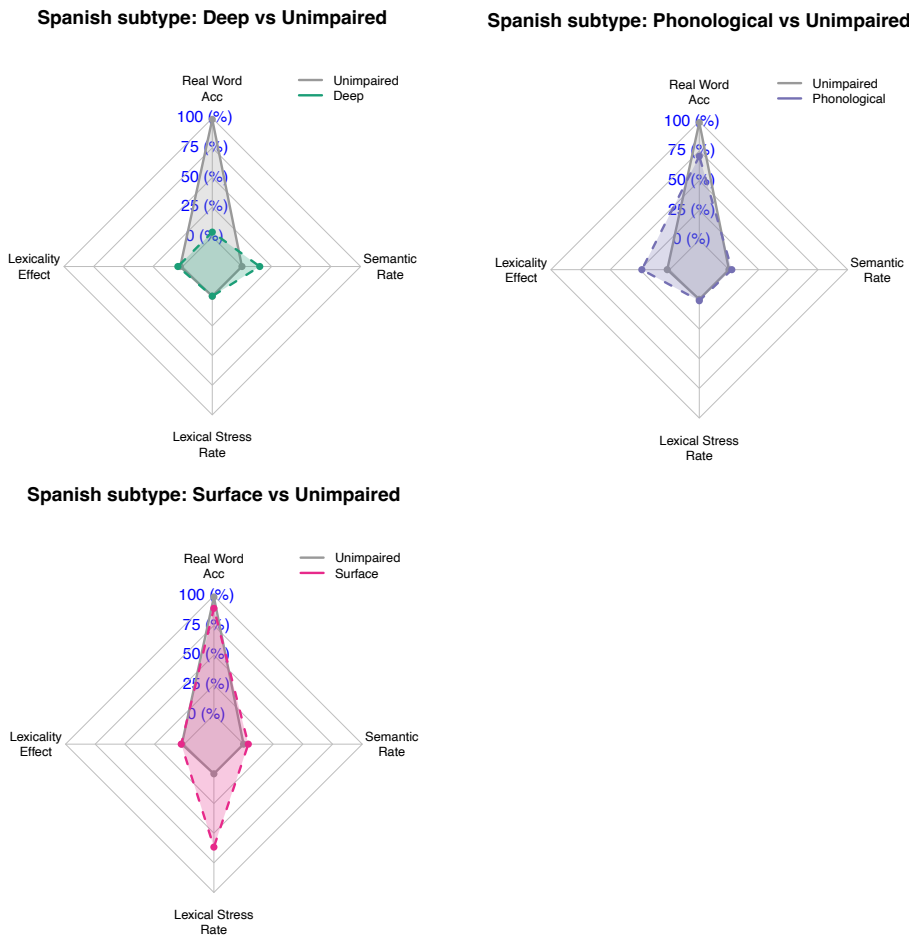


Caption. Acquired dyslexia classifications are shown in English for the BWA and MWA.

Acquired dyslexia subtypes in Spanish were diagnosed using the same principles described for English, with one key difference for identifying surface dyslexia. In Spanish, surface dyslexia was assigned when individuals demonstrated a significant stress-based regularity pattern, reflecting systematic misapplication of lexical stress rules, in the absence of lexicality or semantic effects. Severity of impairment based on overall real-word accuracy (mild, moderate, global-level) is displayed in Figure 7.5 together with the overlapping diagnostic features that characterize these Spanish profiles.

Spanish subtypes in the BWA group showed a somewhat different distribution. Five individuals (45%) exhibited phonological dyslexia, four individuals (36%) showed a surface dyslexia profile driven by lexical stress errors, one individual (9%) demonstrated a deep dyslexia profile based on semantic errors, and one individual (9%) was unimpaired. See Appendix 2 for individual Spanish subtype classifications.

Figure 7.5 Core Diagnostic Features and Severity across Spanish subtypes

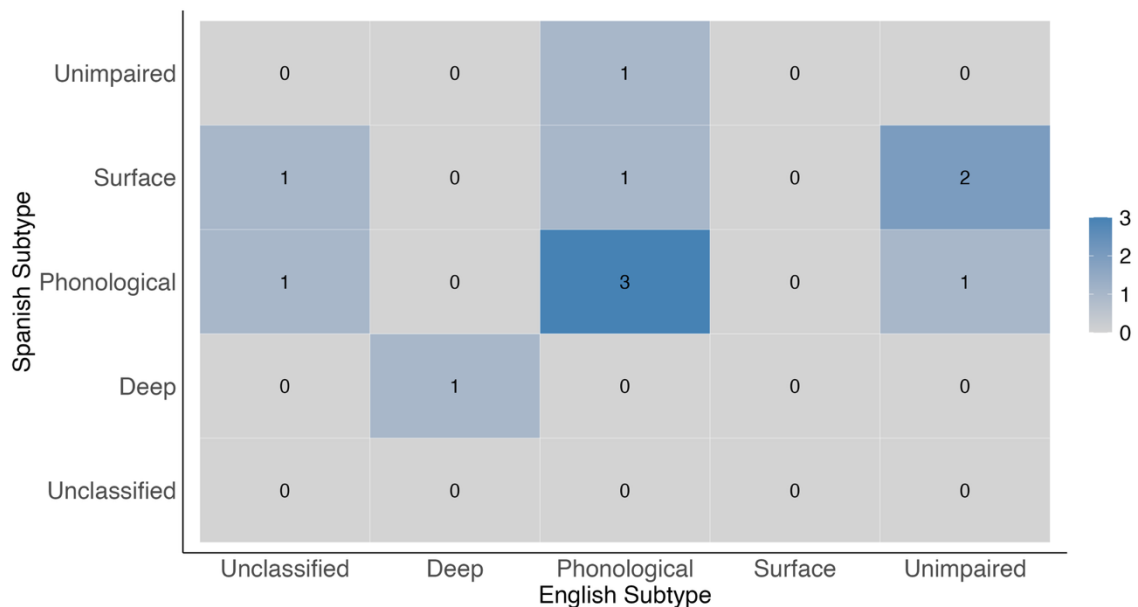


Caption. Overlapping diagnostic features and severity levels underlying Spanish patterns of acquired dyslexia. Features represent the average magnitude of the lexically, lexical stress, and semantic error rate effects that define profiles in Spanish. For example, the phonological plot demonstrates a lexically effect in the absence of a lexical stress and semantic error effect when compared to unimpaired profiles. Severity is represented as the percentage accuracy on real word reading (top point on the diamond). For example, the average phonological profile shows on-average mild severity when compared to the unimpaired group (~25% reduction in real word accuracy) while the deep profile shows on average global severity (i.e., accuracy close to 0 for real word reading).

Of the eleven BWA participants with subtype assignments in both languages, three individuals (27%) showed concordant profiles across English and Spanish, most

commonly phonological patterns in both languages. The remaining eight individuals (73%) demonstrated discordant cross-language profiles. The concordant profiles were either phonological or deep dyslexia in both languages, or a profile in the phonological dyslexia spectrum. A heat map in Figure 7.6 details the various patterns between individual BWA. No single discordant pattern dominated, reflecting substantial heterogeneity in how impairments manifest across languages within individuals.

Figure 7.6 Acquired Dyslexia Subtypes Across English and Spanish



Caption. Concordance between profiles of acquired dyslexia in English and Spanish for the BWA are shown.

In the first part of Aim 1, group-level analyses revealed clear differences in reading ability between the aphasia groups and their respective neurological control groups. Both the BWA and the MWA performed significantly worse on oral reading tasks relative to comprehension tasks. Building on these findings, the present analyses shifted from group-

level severity to individual-level acquired dyslexia profiles to examine how reading impairments may be characterized across languages.

Among the BWA and MWA, phonological dyslexia emerged as the most frequent subtype, consistent with study hypotheses and prior reports in both bilingual (e.g., Goral, 2018; Kuzmina et al., 2019) and monolingual aphasia (e.g., Luzzatti et al., 2006; Madden et al., 2018). This convergence suggests that phonological system disruption is a dominant feature of acquired reading impairment in aphasia, regardless of language background.

However, subtype patterns diverged from expectations at the individual level in bilingual aphasia. Whereas the working hypothesis predicted largely concordant subtype profiles across English and Spanish, most bilingual participants exhibited discordant profiles across languages. Only a minority of individuals showed stable subtype classifications across both languages, and discordant patterns did not converge on a single dominant configuration. Instead, bilingual participants demonstrated substantial heterogeneity in how reading impairments manifested across their two languages.

These findings indicate that although phonological dyslexia predominates at the group level, bilingual aphasia is characterized by considerable individual-level variability in cross-language subtype expression. The implications of this discordance, and its potential relationship to bilingual language history, differential language exposure, and post-stroke language use, are considered in the Discussion. Together, these findings suggest that while phonological dyslexia is the most frequent subtype for both bilingual and monolingual readers with aphasia, the broader subtype landscape is more diverse in bilingual speakers. BWA participants demonstrated not only a higher prevalence of

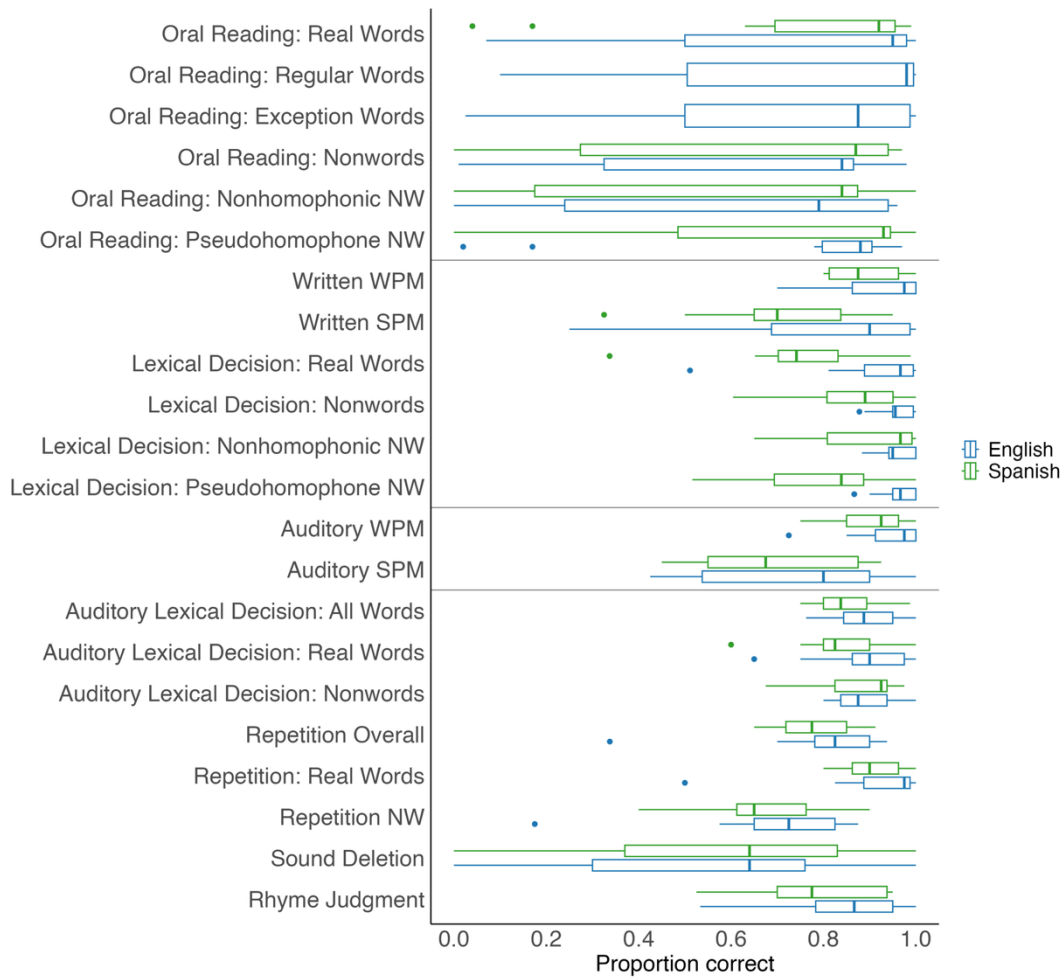
surface-pattern errors in Spanish (n =4) but also a greater likelihood of exhibiting different subtypes across their two languages.

7.2.2. Aim 1.2

Aim 1.2 examined the contribution of non-orthographic semantic and phonological systems to reading performance in bilingual aphasia. Although semantic and phonological predictors of reading accuracy are well established in monolingual aphasia (Beeson et al., 2022; Madden et al., 2018), the present analyses focused specifically on bilingual participants to determine whether bilingual language experience modulates the relative influence of these primary systems during reading. Accordingly, monolingual participants were not included as a comparison group in these models, as the goal was not to re-establish semantic and phonological effects in aphasia generally, but to characterize how these systems support reading within bilingual aphasia.

Group-level oral reading, reading comprehension, semantic, and phonological scores across English and Spanish are available in Figure 7.7. Individual BWA scores are available in Appendices 3–6.

Figure 7.7 BWA Group-level Performance on Reading, Semantic, and Phonological Tasks



Caption. Group (BWA only) boxplots are shown in English and Spanish across oral reading, reading comprehension, semantic, and phonological processing tasks.

7.2.2.1 Oral Reading Models

Separate oral reading models were fit for real words and nonwords to dissociate the contributions of semantic and phonological systems under different processing demands. Real word reading permits support from both lexical–semantic and phonological mechanisms, whereas nonword reading relies primarily on phonological decoding. An additional overall oral reading model was included to characterize the combined influence of these systems on reading accuracy across stimulus types and to facilitate comparison

with broader severity models. Thus, while stimulus-specific models clarify system contributions under different lexical demands, the overall oral reading model provides a global index of how phonological and semantic abilities support reading performance in bilingual aphasia.

In the real word reading model (see Table 7.9 for model output), higher semantic composite scores ($b = 0.95$, $SE = 0.47$, $z = 2.03$, $p = .04$), and higher phonological composite scores ($b = 2.76$, $SE = 0.37$, $z = 7.31$, $p < .001$) had a significant, positive effect on the likelihood of a correct real word reading trial. Language, age, and education were not significant predictors, suggesting that accuracy was not mediated by differences in English and Spanish nor by these individual-specific factors. The random-effects structure revealed substantial variability across both participants ($SD = 1.39$) and items ($SD = 1.44$), indicating that individual characteristics—other than age and education—and stimulus characteristics contributed meaningfully to performance differences.

Table 7.9 Aim 1.2: Oral Reading, Real Words Model

Data	Effect	Term	Estimate	SE	Z	p-value
	Fixed	Intercept	2.78	0.47	5.8	< .001
	Fixed	Semantic Composite	0.95	0.46	2.03	.04
Oreal	Fixed	Phonology Composite	2.76	0.37	7.31	< .001
Reading:	Fixed	Test Lang	-0.5	0.26	-1.88	.05
Real	Fixed	Age (Centered)	0.68	0.48	1.41	.15
Words	Fixed	Education (Centered)	0.16	0.49	0.32	.74
	Random	Item (SD)	1.44			
	Random	Participant (SD)	1.39			

Note. *SE* = Standard Error; *Z* = z-statistic; *SD* = Standard Deviation

For nonword reading (see Table 7.10), only the phonological composite had a significant, positive effect on the likelihood of a correct response ($b = 1.47$, $SE = 0.24$, $z =$

6.07, $p < .001$). Semantic composite scores were not associated with nonword reading ($b = 0.14$, $SE = 0.26$, $z = 0.56$, $p = .57$), consistent with the expectation that nonword decoding relies primarily on phonological processing. No demographic covariates were significant. Random effects again demonstrated large participant-level variability ($SD = 1.73$). Item-level variance was smaller ($SD = 0.59$), suggesting relatively less heterogeneity in accuracy across reading trials.

Table 7.10 Aim 1.2: Oral Reading, Nonwords Model

Data	Effect	Term	Estimate	SE	Z	p-value
Oral Reading: Nonwords	Fixed	Intercept	0.58	0.53	1.08	.27
	Fixed	Semantic Composite	0.14	0.26	0.56	.57
	Fixed	Phonology Composite	1.47	0.24	6.07	< .01
	Fixed	Test Lang	0.16	0.15	1.04	.29
	Fixed	Age (Centered)	0.34	0.59	0.57	.56
	Fixed	Education (Centered)	0.61	0.59	1.02	.30
	Random	Item (SD)	0.59			
	Random	Participant (SD)	1.73			

Note. SE = Standard Error; Z = z-statistic; SD = Standard Deviation

The overall oral reading model (see Table 7.11), collapsing across both word types, revealed a consistent pattern: phonological composite scores strongly predicted overall reading accuracy ($b = 1.93$, $SE = 0.19$, $z = 10.15$, $p < .001$), whereas semantic composite had no effect on the likelihood of a correct response ($b = 0.26$, $SE = 0.2$, $z = 1.28$, $p = .20$). Accuracy did not differ between English and Spanish. Participant-level random effects ($SD = 1.29$) and item-level effects ($SD = 1.14$) remained sizeable, again demonstrating meaningful variability not explained by the fixed effects.

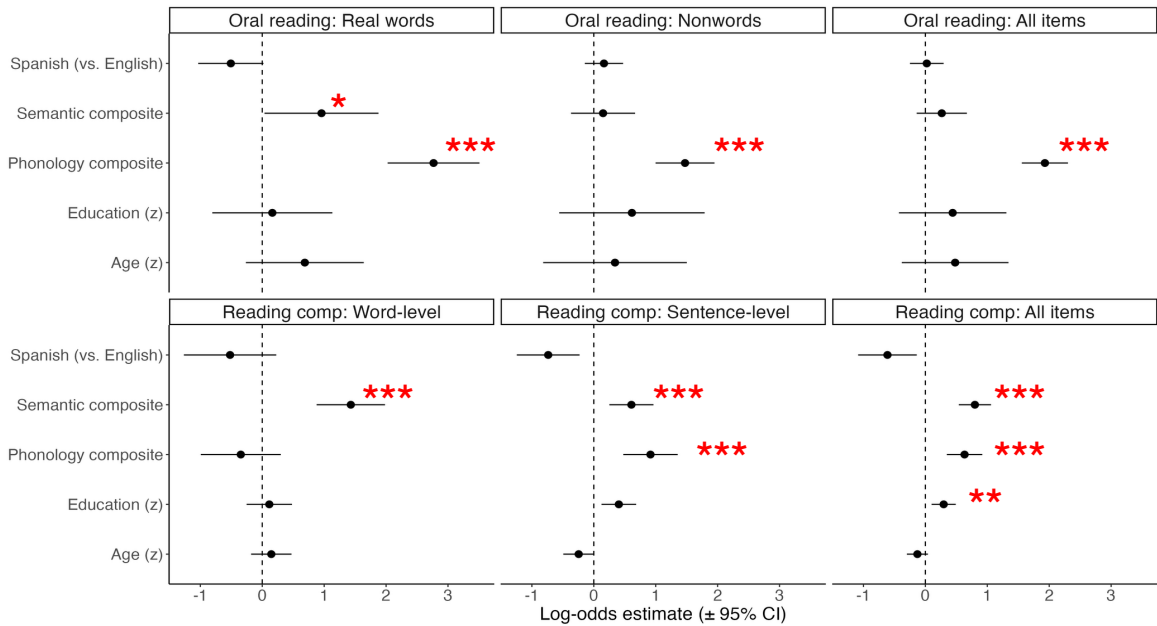
Table 7.11 Aim 1.2: Oral Reading, All Words Model

Data	Effect	Term	Estimate	SE	Z	p-value
All Oral Reading Items	Fixed	Intercept	1.51	0.4	3.74	< .001
	Fixed	Semantic Composite	0.26	0.2	1.28	.2
	Fixed	Phonology Composite	1.93	0.19	10.15	< .001
	Fixed	Test Lang	0.02	0.13	0.16	.86
	Fixed	Age (Centered)	0.48	0.43	1.09	.27
	Fixed	Education (Centered)	0.44	0.44	0.99	.31
	Random	Item (SD)	1.14			
	Random	Participant (SD)	1.29			

Note. *SE* = Standard Error; *Z* = z-statistic; *SD* = Standard Deviation

Collectively, the oral reading models demonstrate a highly consistent pattern in which phonological processing is the primary driver of accuracy across word types, with semantic processing contributing only to real-word reading and no evidence for language-related differences. These patterns are broadly consistent with Madden et al. (2018) which suggests that the phonological-oral reading relationship is a function of impairment in aphasia rather than any bilingualism-specific mechanism. These relationships are summarized in Figure 7.8, which visualizes the direction and relative magnitude of fixed-effect estimates across the oral reading models and provides a point of comparison for the reading comprehension models that follow.

Figure 7.3 Fixed-Effects Estimates Across Oral Reading and Reading Comp Models



Caption. Coefficient plots showing fixed-effect estimates ($\pm 95\%$ confidence intervals) from oral reading and reading comprehension models. Model estimates are shown on the log-odds (logit) scale, where positive values indicate an increased likelihood of a correct response and negative values indicate a decreased likelihood. Red asterisks represent levels of significance, and no asterisks indicate an effect was not significant; * = $p < .05$; ** = $p < .01$; *** = $p < .001$.

7.2.2.2. Reading Comprehension Models

In contrast to oral reading, the reading comprehension models revealed a different configuration of predictors, as reflected in both the model estimates reported below and the corresponding patterns shown in Figure 7.8. The word-level reading comprehension model (see Table 7.12) initially included random intercepts for both participants and items. However, accuracy showed minimal variability across participants, which led to a singular fit and prevented the model from estimating a participant-level random effect. The final model therefore included a random intercept for items only (SD = 1.10). Semantic composite scores significantly predicted word comprehension accuracy ($b = 1.43$, SE =

0.28, $z = 5.07$, $p < 0.001$), indicating that individuals with stronger semantic processing performed better. No other predictors had a significant effect on word comprehension accuracy.

Table 7.12 Aim 1.2: Reading Comprehension, Words Model

Data	Effect	Term	Estimate	SE	Z	p-value
	Fixed	Intercept	3.50	0.35	9.93	< .001
	Fixed	Semantic Composite	1.43	0.28	5.07	< .001
Reading	Fixed	Phonology Composite	-0.34	0.32	-1.05	.29
Comp:	Fixed	Test Lang: Spanish	-0.51	0.38	-1.36	.17
Words	Fixed	Age (Centered)	0.14	0.16	0.88	.37
	Fixed	Education (Centered)	0.11	0.18	0.61	.54
	Random	Item (SD)	1.10			

Note. *SE* = Standard Error; *Z* = z-statistic; *SD* = Standard Deviation

For the sentence-level comprehension model (see Table 7.13), the random-effects structure showed moderate item-level variability ($SD = 0.76$) and relatively small participant-level variability ($SD = 0.19$), consistent with meaningful differences across sentence stimuli but more uniform participant performance. In this case, both semantic ($b = 0.60$, $SE = 0.18$, $z = 3.34$, $p < .001$) and phonological ($b = 0.91$, $SE = 0.22$, $z = 4.08$, $p < .001$) composite scores were significant predictors whereby higher scores were associated with greater likelihood of a correct response (odds ratio) on a sentence comprehension trial. The likelihood of a correct response was lower in Spanish than in English ($b = -0.73$, $SE = 0.25$, $z = -2.84$, $p < .01$). Among the demographic predictors, education was positively associated with sentence comprehension outcomes ($b = 0.40$, $SE = 0.14$, $z = 2.83$, $p < .01$), whereas age had no effect.

Table 7.13 Aim 1.2: Reading Comprehension, Sentences Model

Data	Effect	Term	Estimate	SE	Z	p-value
Reading Comp: Sentences	Fixed	Intercept	1.98	0.21	9.06	< .001
	Fixed	Semantic Composite	0.6	0.18	3.34	< .001
	Fixed	Phonology Composite	0.91	0.22	4.08	< .001
	Fixed	Test Lang: Spanish	-0.73	0.25	-2.84	< .01
	Fixed	Age (Centered)	-0.24	0.12	-1.92	0.05
	Fixed	Education (Centered)	0.4	0.14	2.83	< .01
	Random	Item (SD)	0.76			
	Random	Participant (SD)	0.19			

Note. *SE* = Standard Error; *Z* = z-statistic; *SD* = Standard Deviation

Like the word comprehension model, the overall model (see Table 7.14) initially included random intercepts for participants and items. However, accuracy showed minimal variability across participants, which led to a singular fit and prevented the model from estimating a participant-level random effect. The final model therefore included a random intercept for items only which revealed a moderate amount of variation in accuracy based on stimulus characteristics ($SD = 1.13$). Predictors were consistent with the sentence comprehension model: the semantic composite ($b = 0.80$, $SE = 0.13$, $z = 6.02$, $p < .001$), phonological composite ($b = 0.63$, $SE = 0.14$, $z = 4.33$, $p < .001$), and education ($b = 0.29$, $SE = 0.09$, $z = 2.96$, $p < .01$) all had strong positive effects on the likelihood of correct responses to reading comprehension items whereas testing in Spanish was associated with lower accuracy ($b = -0.61$, $SE = 0.24$, $z = -2.53$, $p = .01$), and age had no effect.

Table 7.14 Aim 1.2: Reading Comprehension, All Items Model

Data	Effect	Term	Estimate	SE	Z	p-value
All Reading Comp Items	Fixed	Intercept	2.63	0.19	13.23	< .001
	Fixed	Semantic Composite	0.80	0.13	6.02	< .001
	Fixed	Phonology Composite	0.63	0.14	4.33	< .001
	Fixed	Test Lang: Spanish	-0.61	0.24	-2.53	.01
	Fixed	Age (Centered)	-0.12	0.08	-1.48	.13
	Fixed	Education (Centered)	0.29	0.09	2.96	< .01
	Random	Item (SD)	1.13			

Note. *SE* = Standard Error; *Z* = z-statistic; *SD* = Standard Deviation

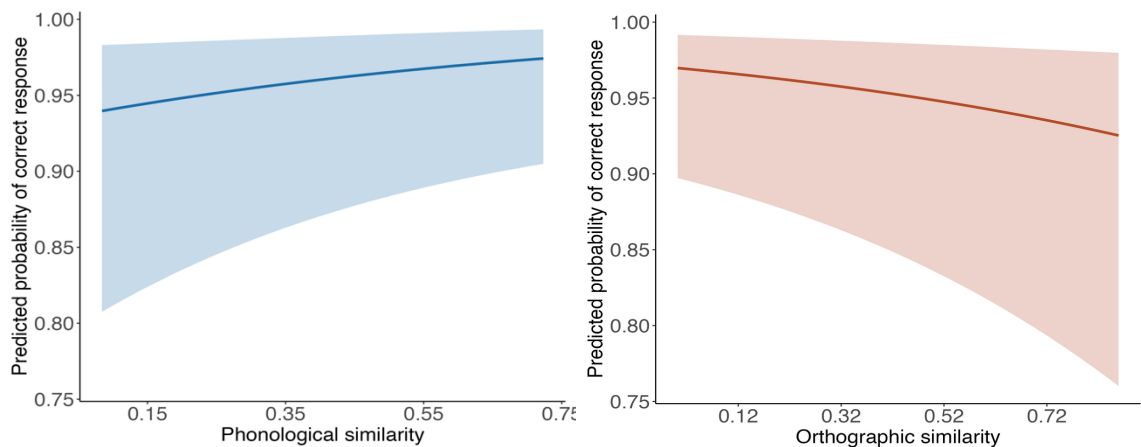
7.2.3. Aim 1.3

The final mixed-effects logistic regression model (see Table 7.15) examined whether cross-language phonological similarity, orthographic similarity, and their interaction predicted single-word reading accuracy across task domains, while controlling for cross-language orthographic and phonological neighborhood density. The model included random intercepts for participants and items and revealed substantial variability at the participant level ($SD = 2.09$) alongside more moderate item-level variability ($SD = 0.88$), indicating that individual differences accounted for a considerable portion of unexplained variance beyond the fixed effects.

In terms of fixed effects, domain was a strong predictor of performance: the likelihood of a correct oral reading trial was significantly lower than for reading comprehension ($b = -1.20$, $SE = 0.11$, $z = -10.72$, $p < .001$). As illustrated in Figure 7.9, greater cross-language phonological similarity was associated with higher predicted accuracy across both domains ($b = 1.38$, $SE = 0.66$, $z = 2.08$, $p = .03$), whereas greater orthographic similarity was associated with reduced accuracy ($b = -1.10$, $SE = 0.43$, $z = -2.54$, $p = .01$). Cross-language orthographic neighborhood density also significantly

predicted higher accuracy ($b = 0.08$, $SE = 0.03$, $z = 2.51$, $p = .01$), while cross-language phonological neighborhood density did not yield a reliable effect. The interaction between phonological and orthographic similarity was not significant, indicating that the main effects shown in Figure 7.9 independently modulate reading accuracy.

Figure 7.4 Effect of Phonological & Orthographic Similarity on Word Reading in BWA



Caption. Predicted probability of a correct response as a function of centered phonological similarity (left) and centered orthographic similarity (right) for real-word oral reading and reading comprehension. Each panel shows the marginal main effect of one similarity metric derived from the mixed-effects model while the other similarity metric and all covariates were held at their centered means. Shaded regions indicate 95% confidence intervals around model-predicted probabilities. Phonological similarity had a positive effect on the likelihood of a correct response while greater orthographic similarity had a significantly negative effect on accuracy.

Statistical Table 10. Aim 1.3: Phonological & Orthographic Similarity Model

Data	Effect	Term	Estimate	SE	Z	p-value
	Fixed	Intercept	3.11	0.65	4.78	< .001
	Fixed	Test Lang: Spanish	0.08	0.07	1.10	.26
	Fixed	Domain (Sum-coded)	-1.20	0.11	-10.72	< .001
	Fixed	Phonological Similarity (Centered)	1.38	0.66	2.08	.03
	Fixed	Orthographic Similarity (Centered)	-1.10	0.43	-2.54	.01
All Single Word Reading	Fixed	Cross-Phonological Neighborhood Density	0.08	0.03	2.51	.01
	Fixed	Cross-Orthographic Neighborhood Density	0.08	0.05	1.57	.11
	Fixed	Phonological Similarity x Orthographic Similarity	0.26	1.50	0.17	.85
	Random	Item (SD)	0.88			
	Random	Participant (SD)	2.09			

Note. *SE* = Standard Error; *Z* = z-statistic; *SD* = Standard Deviation

7.3. Discussion

Aim 1 examined how reading impairment following left-hemisphere stroke manifests in bilingual aphasia by situating bilingual outcomes within a broader aphasia framework and then isolating bilingual-specific influences on reading. Across Aims 1.1–1.3, several core patterns were shared between the BWA and MWA, indicating that disruption to modality-independent semantic and phonological systems is a fundamental consequence of stroke rather than a bilingual-specific effect. Relative to neurological controls, both aphasia groups exhibited pervasive reading impairment, disproportionate difficulty with oral reading compared to reading comprehension, and a predominance of phonologically mediated reading deficits. These shared patterns align with predictions of the triangle model and the Primary Systems Hypothesis, which posit that reading breakdown arises from damage to central semantic and phonological systems that also support spoken language (Seidenberg & McClelland, 1989; Patterson & Lambon Ralph, 1999; Lambon Ralph & Patterson, 2007; Woollams, 2014).

At the same time, the expression of these impairments differed in systematic ways that highlight the influence of bilingual language experience. Although both aphasia groups showed a robust oral-reading disadvantage, the magnitude of this domain difference was attenuated in bilingual aphasia relative to monolingual aphasia in English, suggesting that reading experience across two languages may modulate how phonological impairment manifests during reading aloud. In addition, while phonological dyslexia was the most frequent subtype in both groups, bilingual participants frequently exhibited discordant subtype profiles across English and Spanish, indicating greater heterogeneity in cross-

language expression of reading impairment than has been emphasized in prior work. These differences suggest that bilingualism does not alter the core mechanisms underlying reading impairment, but rather shapes how shared impairments are filtered through languages with distinct orthographic and phonological demands.

Finally, the BWA showed patterns that cannot exist in monolingual aphasia, providing direct evidence for continued language non-selective access following stroke. Non-orthographic semantic and phonological abilities predicted reading performance similarly across English and Spanish, and graded cross-language phonological and orthographic similarity modulated reading accuracy across tasks. Together, these findings indicate that integrated bilingual lexical representations remain active post-stroke and support the Bilingual Interactive Activation for Aphasia (BIAA) framework proposed in Chapter 6, in which central language impairment interacts with bilingual lexical organization to shape reading outcomes (Dijkstra & van Heuven, 1998, 2002; Grainger et al., 2010; Dijkstra et al., 2019).

7.3.1. Patterns of Alexia and Acquired Dyslexia in Aphasia

7.3.1.1. Reading Impairment Across Domains

Relative to neurological controls, both the BWA and MWA demonstrated pervasive reading impairment, suggesting that reduced reading accuracy is a core consequence of left-hemisphere stroke rather than a bilingual-specific effect. In bilingual aphasia, this impairment remained robust after controlling for age, education, and premorbid reading ability, underscoring that post-stroke reading deficits cannot be

attributed solely to differences in baseline literacy or language experience. A notable contribution of the present analyses is the explicit modeling of premorbid reading ability in bilingual aphasia. To our knowledge, few group-level studies of bilingual alexia have directly incorporated premorbid literacy measures as independent predictors of post-stroke reading performance, despite longstanding recognition that bilingual experience is highly variable (Paradis, 2004; Kuzmina et al., 2019). In the present study, premorbid reading ability explained unique variance in reading accuracy above and beyond aphasia status, reading domain, and demographic factors, indicating that the strength of pre-injury reading systems continues to constrain performance following stroke. This finding suggests that premorbid reading ability is not merely a background characteristic, but a critical component of the system whose integrity shapes post-stroke outcomes. Importantly, this modeling decision also highlights a key methodological distinction between bilingual and monolingual aphasia. Premorbid reading ability was not included as a predictor in the monolingual models, as all monolingual participants had acquired high levels of literacy in English, making uniform assumptions about premorbid reading skill reasonable. In contrast, bilingual participants varied widely in the timing, context, and depth of reading experience across their two languages. The fact that premorbid reading ability emerged as a significant predictor in bilingual aphasia underscores the importance of explicitly modeling bilingual language history rather than assuming comparable literacy across languages. These findings suggest that premorbid bilingual experience exerts an independent influence on post-stroke reading performance and should be incorporated into future group-level studies of bilingual alexia.

Across aphasia groups, oral reading was disproportionately impaired relative to reading comprehension. This modality asymmetry is consistent with prior work showing that reading comprehension varies across levels of complexity and individuals, and that reading tasks differ in the cognitive–linguistic demands they impose (Webb & Love, 1983; Meteyard et al., 2015; Webster et al., 2022). Reading aloud places additional demands on phonological encoding and output processes. Under a primary systems account, disruption to phonological representations should therefore have especially direct consequences for oral reading performance relative to comprehension tasks that can be supported by residual semantic processing (Patterson & Lambon Ralph, 1999; Lambon Ralph & Patterson, 2007). Critically, this oral-reading disadvantage was observed in both bilingual and monolingual aphasia, demonstrating that the domain effect reflects aphasia-related vulnerability rather than bilingual language organization. However, direct comparison of bilingual and monolingual aphasia revealed that the magnitude of the oral reading versus comprehension difference in English was smaller in bilingual aphasia, suggesting that bilingual reading experience may modulate how phonological impairment manifests during reading aloud without altering the underlying mechanism.

7.3.1.2. Acquired Dyslexia Subtype Distributions and Concordance

The subtype classification results provide converging evidence for phonological disruption as a core feature of acquired reading impairment following left-hemisphere stroke. Phonological dyslexia emerged as the most frequent profile among bilingual participants in both English and Spanish, mirroring the distribution observed in the monolingual aphasia group in the present study as well as prior monolingual cohort

investigations (Brookshire et al., 2014; Madden et al., 2018; Beeson et al., 2022). This convergence across bilingual and monolingual aphasia suggests that vulnerability of phonological processing networks represents a stroke-general mechanism underlying alexia rather than an effect driven by bilingual language organization. In this respect, bilingualism does not appear to fundamentally alter the type of reading impairment that most commonly follows stroke but instead shapes how that impairment is expressed across languages.

Despite this shared dominance of phonological dyslexia, the bilingual subtype landscape was substantially more heterogeneous than that observed in monolingual aphasia. In the monolingual group, subtype classifications reflected a relatively stable mapping between phonological impairment and reading performance within a single orthographic system. By contrast, only a minority of bilingual participants exhibited concordant subtype profiles across English and Spanish, and discordant profiles did not cluster around a single dominant configuration. These findings appear to contradict the prior literature and the hypotheses for Aim 1.1 which suggested that BWA in the study should have demonstrated mostly concordant profiles across languages (Goral, 2019). Importantly, this prior consistency from the literature has largely been inferred from single-case or small case-series studies that lack systematic comparisons of BWA and matched neurological controls. The present cohort-level results suggest that subtype *discordance* may be more common than previously appreciated when post-stroke bilingual reading performance is evaluated relative to appropriate neurological baselines.

Indeed, one factor that likely contributed to the higher prevalence of discordant subtype profiles in the present study was the decision to interpret post-stroke bilingual reading performance against the performance of bilingual controls rather than relying on within-individual or across-language contrasts of pre and post-morbid reading ability. This approach may have increased sensitivity to subtle, language-specific deviations in reading accuracy and error patterns that would otherwise be obscured when performance is evaluated only relative to an individual's baseline. In doing so, the present analyses may have revealed graded differences in impairment severity or diagnostic features that contribute to discordant subtype classifications across languages, even when the underlying impairment is shared. These findings suggest that prior reports of predominantly concordant profiles may partly reflect methodological constraints rather than true uniformity of impairment expression across languages.

A second, complementary explanation concerns heterogeneity in bilingual literacy experience. Despite efforts to recruit individuals with comparable language combinations, the BWA varied widely in their L1/L2, age of acquisition, and self-reported premorbid reading abilities. Lived experiences such as differential access to formal education, literacy instruction in only one language, or later acquisition of reading in a heritage language may have resulted in markedly different degrees of lexical knowledge across languages prior to stroke. When a shared, phonologically vulnerable reading system is disrupted by brain injury, these premorbid differences may be amplified, producing distinct patterns of impairment across languages that manifest as discordant subtype classifications. This interpretation is also consistent with the findings from the first part of Aim 1.1, which

demonstrated that premorbid reading ability independently predicted post-stroke reading accuracy in bilingual aphasia. Taken together, these results suggest that subtype discordance in bilingual aphasia may reflect the interaction of stroke-induced impairment with heterogeneous premorbid literacy histories rather than fundamentally different underlying mechanisms across languages.

Finally, the Spanish surface-pattern profiles require careful interpretation. In English, surface dyslexia is diagnosed largely through a regularity effect tied to exception word processing (Coltheart et al., 1983; Coltheart et al., 2001). As Madden et al. (2018) notes, however, surface dyslexia following left-hemisphere stroke is a much rarer diagnosis. Indeed, in the present MWA cohort, there were no individuals identified with surface dyslexia. Importantly, Spanish is a transparent orthography that contains few irregularly spelled words. Surface dyslexia must therefore be diagnosed using other markers, most prominently lexical stress regularization errors or pseudohomophone and homophone confusions (Ferrerres et al., 2005; Ferrerres et al., 2012; Iribarren et al., 1996). This diagnostic reality creates a bilingual-specific risk. Stress errors can reflect post-stroke lexical impairment, but they can also reflect low familiarity with word pronunciation while reading aloud that may be linked to incomplete literacy acquisition. The present results show that a sizeable proportion of the BWA met stress-based criteria for surface dyslexia in Spanish, and the accompanying case-level notes indicate clustering in individuals with L1 English literacy histories and later Spanish learning or heritage experience. As a result, interpreting these cases as “true” surface dyslexia in the Spanish remains unlikely. These findings highlight an assessment limitation identified in the background chapters: the

criteria for Spanish surface dyslexia were derived from the monolingual Spanish stroke literature, and they may not cleanly separate premorbid literacy experiences from stroke-induced breakdown in bilingual readers (Ferrerres et al., 2005; Ferreres et al., 2012; Iribarren, 2007).

One promising direction for future work would be to dissociate lexical stress knowledge from oral reading performance by incorporating tasks that assess lexical stress processing independently of orthographic decoding. For example, BWA could complete auditory stress discrimination or stress identification tasks (e.g., choosing the correctly stressed form of a spoken word or judging stress placement in minimal pairs) alongside reading aloud. If stress errors observed during oral reading reflect post-stroke disruption to lexical representations, comparable impairments should emerge in auditory stress judgments. In contrast, intact stress processing in the auditory domain paired with stress regularization during reading aloud would suggest that these errors are more strongly tied to premorbid literacy experience and orthography–phonology mappings rather than to stroke-induced surface dyslexia per se.

Taken together, subtype distributions and concordance patterns suggest that while phonological dyslexia represents a common outcome of stroke across monolingual and bilingual aphasia, bilingualism introduces additional sources of variability in how that impairment is expressed across languages. These findings underscore the importance of evaluating bilingual reading performance relative to neurological control norms and of explicitly incorporating premorbid literacy history when interpreting acquired dyslexia profiles.

7.3.2. Non-orthographic Semantic and Phonological Predictors

Aim 1.2 tested whether individual differences in central semantic and phonological abilities predict reading performance in bilingual aphasia, as predicted by the Primary Systems Hypothesis and the triangle model of reading. Specifically, semantic abilities were hypothesized to support real word reading and reading comprehension, whereas phonological abilities were expected to play a stronger role in oral reading of phonologically demanding items such as nonwords. Critically, these relationships were expected to emerge similarly in English and Spanish, consistent with the operation of shared, modality-independent systems across languages.

The results largely supported these hypotheses. Across oral reading models, phonological composite performance robustly predicted accuracy for real words, nonwords, and overall oral reading, whereas semantic composite performance selectively predicted real word reading. This division of labor closely matches the architecture of the triangle model, in which orthographic processing depends on interactions among central semantic and phonological systems rather than language- or modality-specific reading mechanisms (Seidenberg & McClelland, 1989; Patterson & Lambon Ralph, 1999). These findings also align with monolingual aphasia research showing that non-orthographic phonological impairment can account for lexicality effects in oral reading, while semantic integrity selectively supports real-word processing (Crisp & Lambon Ralph, 2006; Rapcsak et al., 2009; Madden et al., 2018).

Importantly, the present findings extend this literature by demonstrating that these system-level relationships operate similarly across both languages in bilingual aphasia.

Neither the strength nor the direction of semantic and phonological predictors differed reliably between English and Spanish, indicating that central semantic and phonological systems constrain reading performance in a language-general manner. These findings suggest that bilingual reading impairments are governed by the same modality-independent mechanisms proposed for monolingual aphasia, rather than by language-specific orthographic systems. In this sense, the results provide direct support for bilingual extensions of the Primary Systems Hypothesis, including the BIAA framework, which assumes shared semantic and phonological representations that jointly support reading across languages.

Reading comprehension models showed a complementary configuration of predictors. Word-level comprehension was primarily predicted by semantic ability, whereas sentence-level comprehension was predicted by both semantic and phonological composites. This pattern is consistent with prior monolingual work suggesting that phonological processing contributes more strongly as linguistic complexity and sequencing demands increase (Madden et al., 2018). The reduced participant-level variability observed in some comprehension models further suggests that these tasks were more constrained by stimulus-level properties than by individual differences, highlighting differences in how semantic and phonological resources are recruited across reading modalities.

Notably, global aphasia severity did not consistently align with reading outcomes across models based on WAB aphasia quotient scores. This dissociation is not unexpected under a primary systems account as the framework predicts that reading performance should depend on the integrity of central semantic and phonological systems. However, it

does not require that a global severity index—such as the WAB—will be equally sensitive to the specific components that most strongly support reading (Patterson & Lambon Ralph, 1999; Lambon Ralph & Patterson, 2007). The present findings therefore suggest that reading impairment in bilingual aphasia cannot be fully characterized by overall aphasia severity alone and underscore the value of targeted, non-orthographic measures for explaining variability in reading performance.

Finally, although monolingual participants were not included in these models, this decision was intentional rather than a limitation. The relationships between semantic ability, phonological ability, and reading performance in monolingual aphasia are already well documented (e.g., Madden et al., 2018; Beeson et al., 2022). Aim 1.2 instead sought to determine whether these same system-level relationships extended to bilingual aphasia and whether they did so across both languages within individuals. The convergence of phonological predictors across English and Spanish suggests that bilingual language experience does not fundamentally alter the architecture linking central language systems to reading. Instead, these findings indicate that bilingual aphasia is constrained by the same core mechanisms that govern reading in monolingual aphasia according to an integrated bilingual language system.

7.3.3. Cross-language Similarity and Bilingual Interactive Activation

Aim 1.3 tested the hypothesis that bilingual word recognition mechanisms remain active following stroke and that cross-language overlap in phonology and orthography would modulate reading accuracy in bilingual aphasia. Specifically, greater phonological and/or orthographic overlap between English and Spanish was expected to facilitate

reading accuracy. The present findings partially supported these predictions and, in doing so, provide clear evidence for preserved language non-selective activation in bilingual aphasia in the reading modality.

Consistent with the hypotheses in Chapter 6, greater cross-language phonological similarity predicted higher reading accuracy across domains. This facilitative effect aligns closely with classic demonstrations of cognate facilitation in healthy bilingual readers, in which shared phonological and semantic representations promote faster and more accurate word recognition (Beauvillain & Grainger, 1987; de Groot et al., 2000; Dijkstra et al., 2010). Importantly, phonological similarity in the present study was quantified using a graded similarity matrix rather than categorical cognate status. As a result, this effect captures sublexical phonological overlap that participants are unlikely to be consciously aware of. The fact that such fine-grained phonological similarity reliably predicted reading accuracy suggests that bilingual readers with aphasia continue to activate shared phonological representations across languages during word recognition, even in the absence of overt cognate structure. These findings therefore provide strong support for models that assume integrated phonological representations and language non-selective access, as proposed in the BIA+ model and extended here to the BIAA framework (Dijkstra & van Heuven, 1998, 2002; Grainger et al., 2010).

In contrast, greater cross-language orthographic similarity was associated with reduced reading accuracy. This inhibitory effect is consistent with interference patterns observed for interlingual homographs in healthy bilinguals, where shared orthographic form but divergent phonological or semantic mappings increase competition during lexical

selection (Dijkstra et al., 1999; Dijkstra et al., 2000; Voga & Grainger, 2007). Within a bilingual interactive activation framework, orthographic similarity may increase activation of competing lexical candidates at early, sublexical stages of processing, thereby placing greater demands on inhibitory control and selection mechanisms. Following stroke, when inhibitory processes or representational precision may be compromised, this increased competition may be especially costly for accurate word recognition (Keane & Kiran, 2015).

At the same time, cross-language orthographic neighborhood density exerted a facilitative effect on reading accuracy. This pattern suggests that orthography can exert both inhibitory and facilitative influences depending on the level of representation involved. Whereas orthographic similarity between translation equivalents may heighten direct competition, a richer cross-language orthographic neighborhood may support lexical activation by increasing the number of partially overlapping representations that converge on the target word. This interpretation is consistent with prior evidence that greater orthographic neighborhood density can facilitate word recognition by strengthening activation dynamics within the lexicon (Grainger & Dijkstra, 1992; van Heuven et al., 1998). Together, these findings indicate that orthographic overlap is not uniformly detrimental or beneficial; rather, its effect may depend on whether overlap increases direct competition or supports activation through distributed neighborhood structure.

Notably, the absence of a significant interaction between phonological and orthographic similarity supports an independent account of these effects in the present dataset. Phonological facilitation and orthographic interference appear to independently modulate reading accuracy, consistent with models in which phonological and orthographic

information exert separable influences during word recognition. These domain-general effects also mirror the oral reading and reading comprehension differences observed in Aim 1.1, where oral reading showed greater vulnerability than reading comprehension, underscoring the central role of phonological processing demands during reading aloud.

Taken together, these findings suggest that bilingual word recognition mechanisms—including language non-selective activation, cross-language facilitation, and competition—remain active following stroke and continue to shape reading performance in bilingual aphasia. Crucially, these effects cannot be observed in monolingual aphasia and therefore aim 1.3 provides unique evidence for bilingual-specific dynamics operating within a shared lexical system. By demonstrating that graded phonological and orthographic overlap predicts reading accuracy in bilingual aphasia, Aim 1.3 offers direct support for the BIAA framework and reinforces the view that post-stroke reading impairments unfold within an integrated bilingual language architecture rather than separate, language-specific reading systems.

7.3.4. Integrating Aim 1 within the BIAA framework

Across Aims 1.1–1.3, phonological processing emerges as the dominant predictor of reading accuracy. Phonological dyslexia was the most common subtype across languages, oral reading showed greater impairment than reading comprehension, phonological composite scores were the most consistent predictors of oral reading accuracy, phonological ability contributed to sentence comprehension, and cross-language phonological similarity facilitated single-word reading. This convergence supports the argument developed in Chapters 2 and 3 that central phonological impairment is a unifying

feature across spoken and written language deficits following left-hemisphere stroke. It also offers a mechanistic explanation for the high prevalence of phonological dyslexia observed in aphasia cohorts (Crisp & Lambon Ralph, 2006; Rapcsak et al., 2009; Beeson et al., 2022; Brookshire et al., 2014; Madden et al., 2018). At the same time, Aim 1 bridges primary-systems accounts and bilingual interactive activation accounts. The BIAA framework assumes shared semantic, phonological, and orthographic systems, and it assumes non-selective bilingual activation that is subsequently constrained through language nodes and task schemas (Dijkstra & van Heuven, 1998, 2002; Seidenberg & McClelland, 1989). The Aim 1 results provide early support for this integrated architecture by demonstrating both primary-systems prediction and cross-language activation effects in the same cohort.

Taken together, the Aim 1 findings suggest that bilingual reading systems remain organized according to the principles articulated in the BIAA framework, but that these systems operate under altered constraints following stroke. The BIAA assumes shared semantic, phonological, and orthographic representations with language-nonspecific activation and competition resolution. Under this architecture, damage to modality-independent components would be expected to affect both languages, yielding broadly similar patterns of difficulty across languages. In that sense, concordant reading profiles can be viewed as a natural outcome of shared representational substrates.

However, the present results demonstrate that concordant dyslexia profiles are not the predominant outcome in bilingual aphasia. Instead, many BWA exhibited discordant acquired dyslexia profiles across English and Spanish. At first glance, this pattern may

seem inconsistent with accounts in which reading impairment arises from damage to shared semantic, phonological, and orthographic systems, as such models might predict broadly similar impairment profiles across languages.

The present findings suggest a more nuanced interpretation. Lesioning the bilingual reading system does not simply reduce reading accuracy uniformly across languages. Rather, stroke alters the efficiency, resting activation levels, and competitive dynamics of shared representational systems. The behavioral expression of this damage is then filtered through individuals' premorbid reading experience and constrained by post-stroke reading and literacy engagement. As a result, bilingual readers may exhibit either concordant or discordant acquired dyslexia profiles, even when the underlying representational architecture is shared. From this perspective, discordant profiles do not contradict shared-representation models such as the BIAA. Instead, they reflect the interaction between damaged modality-independent systems and language-specific learning histories that shape how impairment manifests across languages.

In furtherance of this view, the present study showed that premorbid reading ability independently predicted post-stroke reading accuracy, indicating that the strength and specificity of orthographic representations prior to injury continued to constrain performance after stroke. This finding provides a principled explanation for why discordant profiles can arise even within a relatively homogeneous bilingual cohort (e.g., Spanish-English BWA mostly living in the Northeast US). Differences in literacy acquisition, instructional context, and habitual reading across languages may lead to asymmetries in orthographic processing skills that become unmasked when central semantic and

phonological systems are compromised. From this perspective, discordant profiles do not contradict shared-representation models; rather, they reveal how bilingual background factors modulate the expression of impairment within a damaged, but still integrated, reading system.

These findings suggest that bilingual aphasia cannot be fully characterized by assuming uniform effects of stroke across languages, even when languages share scripts and participants share sociolinguistic contexts. Instead, bilingual reading outcomes reflect the combined influence of lesion-induced disruption, premorbid literacy experience, and post-stroke language engagement operating within a shared but altered representational architecture. This framework reconciles the presence of both concordant and discordant profiles in bilingual aphasia and underscores the importance of explicitly modeling premorbid reading history when interpreting post-stroke reading impairment.

7.3.5. Limitations & Future Directions

Several limitations should be considered when interpreting the results of Aim 1, and these limitations point directly to important directions for future work on bilingual alexia. First, although the present study explicitly controlled for premorbid reading ability in multiple analyses, premorbid literacy experience in bilinguals is difficult to capture fully. Self-reported measures of reading ability and language use cannot fully reflect differences in quality of literacy exposure, instructional context, or depth of lexical knowledge across languages. This limitation is particularly relevant for interpreting Spanish reading outcomes in participants with later acquisition or heritage language backgrounds, where reduced formal literacy experience may interact with post-stroke impairment in ways that

are not fully separable using currently available measures.

Relatedly, the diagnostic criteria used to classify acquired dyslexia subtypes in Spanish were necessarily adapted from the monolingual Spanish stroke literature. While stress-based regularity patterns provide an important marker of lexical processing in Spanish, these criteria may be insufficiently specific for bilingual readers whose premorbid lexical representations differ from those of monolingual speakers. As shown in Aim 1.1, stress-related errors clustered in individuals with particular bilingual language histories, raising the possibility that some profiles classified as surface dyslexia reflect limited premorbid lexical knowledge in Spanish rather than consequences of stroke. Future work would benefit from bilingual-normed diagnostic frameworks that explicitly incorporate language history, literacy experience, and age of acquisition when interpreting subtype patterns.

Another limitation concerns the assessment materials used in Aim 1.2. The semantic and phonological predictors were derived from standardized psycholinguistic measures that are largely direct translations across English and Spanish. In addition, within language, some tasks—such as auditory and written word–picture matching—shared stimulus sets. Although task order was counterbalanced and shared-stimulus assessments were administered on separate testing days to minimize practice effects, the use of overlapping lexical items may nonetheless have influenced performance on the tasks. Specifically, shared stimuli could inflate cross-task correlations or obscure modality-specific contributions to reading performance. Replicating these analyses using assessments with non-overlapping stimuli, as well as measures that are culturally and

linguistically developed to be comparable would strengthen future inferences about the strength of semantic and phonological predictors across languages.

Another limitation concerns the measurement of aphasia severity. Global severity indices such as the WAB provide an important clinical reference point, but the present results demonstrate that they do not always align with reading impairment profiles or with the phonological and semantic deficits most predictive of reading performance. Practice effects and limited sensitivity to fine-grained linguistic processing may obscure relationships between spoken and written language impairment. Future studies should continue to integrate targeted non-orthographic measures alongside standard aphasia batteries to better capture the mechanisms underlying reading deficits in bilingual aphasia.

Finally, although Aim 1 provides strong evidence for cross-language similarity effects in bilingual aphasia, the study design does not permit direct comparison of the magnitude of these effects to bilingual neurological controls bilingual readers (control performance was at ceiling for the oral reading and reading comprehension tasks). As a result, it remains unclear whether cross-language facilitation and interference effects are attenuated, merely preserved, or exaggerated following stroke. This limitation motivates Aim 2, which used eye tracking to examine the time course of bilingual lexical activation during sentence reading and to determine how stroke alters the dynamics of competition and selection predicted by bilingual interactive activation models.

8. AIM 2: EYE TRACKING AS A TOOL TO ASSESS REAL-TIME READING COMPREHENSION

8.1. Method

8.1.1. Participants

Participants were 20 MWA, 16 MNC, 8 BWA, and 10 BNC. The same MWA and MNC contributed data to Aim 1.1. Five of the 11 BWA who contributed data to Aim 1 completed the study at a distance and could not travel to Boston to complete eye tracking. Two additional BWA completed the eye tracking but had not completed the behavioral testing for inclusion in Aim 1 (i.e., 8 total BWA for Aim 2). Similarly, an additional 3 BNC completed the eye tracking in Aim 2 but had not completed the behavioral testing for inclusion in Aim 1 and 1/8 BNC (from Aim 1.1) did not complete eye tracking. Therefore, 8 BWA and 10 BNC contributed data to Aim 2. As in Aim 1, all participants were 18-85 years old and demonstrated adequate hearing and normal or corrected-to-normal vision to complete study procedures. Participants were excluded if they reported i) a neurological illness (other than stroke in the MWA and BWA) or neuropsychiatric disorder (e.g., schizophrenia) that could interfere with study performance; or ii) a learning disability, especially developmental dyslexia that could have caused reading difficulties across the lifespan. Before enrolling in the study, participants provided written informed consent in accordance with the Boston University Charles River Campus Institutional Review Board (Reference Number: 3309E).

The MWA group consisted of 20 individuals (8 female, 12 male) with a mean age of 63 years (SD = 7.6; range: 50–77) and an average of 13 years of education (SD = 2; range: 13–22). All participants were in the chronic stage of recovery (>6 months post-onset), with a mean time post-onset of 113.5 months (SD = 114; range: 22–565). WAB-R AQ scores indicated mild to moderate aphasia severity (mean = 90.4, SD = 8.8, range: 63.1-100). According to WAB-R diagnostic criteria, 9 participants were classified as having anomic aphasia and 2 as having conduction aphasia; the remaining individuals fell within the NABW range due to very mild impairment. See Table 8.1 for individual demographic characteristics for the MWA group.

The MNC group consisted of 16 individuals (11 female, 5 male) who had a mean age of 61.8 years (SD = 8.7, range: 47-73) and an average of 18.5 years of education (SD = 3.2, range: 14-27). The MNC group was matched to the MWA group on age and education. Given the small and unequal sample sizes, Mann-Whitney U tests were used to assess demographic differences. Results indicated no significant differences in age ($U = 166.5, p = .85$) or education ($U = 115.0, p = .14$). As part of the inclusion criteria, all MNC demonstrated intact cognition by scoring within normal limits on the MoCA. See Table 8.2 for individual demographic characteristics for the MNC group.

The BWA group consisted of 8 individuals (3 female, 5 male) who had a mean age of 56.6 years (SD = 18.7, range: 27-80) and an average of 16.2 years of education (SD = 2.8, range: 12-19). All BWA were in the chronic stage of recovery and had a mean time post-onset of 74.1 months (SD = 35.1, range: 41-138). 5 individuals reported Spanish as their L1 and the mean age of second language acquisition was 15 years (SD = 6.6, range:

3-21 years). WAB-R AQ scores revealed moderate aphasia severity in English (mean = 67.6, SD = 22.1, range: 42.9-98) and comparable severity in Spanish (mean = 64.6, SD = 22.3, range: 39.3-89.0). Based on WAB-R criteria, aphasia classifications were: 1 anomic, 3 Broca's, 2 conduction, and 2 NABW in English and 4 anomic, 3 Broca's, and 1 Wernicke's in Spanish See Table 8.3 for individual demographic characteristics for the BWA group.

The BNC group consisted of 10 individuals (7 female, 3 male) who had a mean age of 39.9 years (SD = 16.0, range: 24-72) and an average of 18.8 years of education (SD = 4.5, range: 12-28). 7/8 BNC participants who contributed data to Aim 1.1 also completed eye tracking; the additional three participants had only completed eye tracking. The BNC group was matched to the BWA group on age and education. Given the small and unequal sample sizes, Mann–Whitney U tests were used to assess demographic differences. Results indicated no significant differences in age ($U = 20.0, p = .05$) or education ($U = 58.5, p = .24$) between the groups. All BNC participants demonstrated intact cognition by scoring within normal limits on the MoCA except BNC11 who scored one point below the cutoff score of 26. See Table 8.4 for individual characteristics for the BNC group.

Table 8.1. MWA Demographic Characteristics

ID	Sex	Hand	Age	Edu	MPO	Race	Ethnicity	WAB AQ	WAB-R Classification
MWA01	F	R	70	22	89	White	Non-Hispanic	97.7	NABW
MWA02	M	L	71	17	101	White	Non-Hispanic	91.2	Anomic
MWA03	F	L	53	20	47	White	Non-Hispanic	92.2	Anomic
MWA04	F	R	63	16	67	White	Non-Hispanic	97.7	NABW
MWA05	F	R	62	18	180	White	Non-Hispanic	96.4	NABW
MWA06	M	R	71	16	85	White	Non-Hispanic	96.3	NABW
MWA07	F	R	54	19	22	White	Non-Hispanic	100	NABW
MWA08	M	R	51	16	56	White	Non-Hispanic	93.8	NABW
MWA09	M	R	67	20	94	White	Non-Hispanic	85.2	Anomic
						Black or African			
MWA10	M	R	68	13	72	American	Non-Hispanic	88.6	Anomic
MWA11	F	L	50	16	199	White	Non-Hispanic	86.9	Anomic
MWA12	M	R	77	15	63	White	Non-Hispanic	73.5	Conduction
						Black or African			
MWA13	F	R	61	16	105	American	Non-Hispanic	86.2	Anomic
MWA14	M	R	73	18	60	White	Non-Hispanic	92.1	Anomic
MWA15	M	R	61	16	565	White	Non-Hispanic	91.3	Anomic
MWA16	F	L	62	16	134	White	Non-Hispanic	96.1	NABW
						Black or African			
MWA17	M	R	66	16	44	American	Non-Hispanic	88.7	Anomic
MWA18	M	R	66	16	87	White	Non-Hispanic	98	NABW
MWA19	M	R	60	16	81	White	Non-Hispanic	63.1	Conduction
MWA20	M	R	54	19	119	White	Non-Hispanic	94.6	NABW
Mean			63	17.0	113.5			90.4	
SD			7.6	2.0	114.7			8.8	

Note. *Edu* = Education (yrs); *MPO* = Months post-onset; *NABW* = Not Aphasic by WAB

Table 8.2. MNC Demographic Characteristics

ID	Sex	Hand	Age	Edu	Race	Ethnicity	MoCA
MNC01	M	R	49	18	White	Non-Hispanic	30
MNC02	M	R	62	16	White	Non-Hispanic	30
MNC03	F	R	66	16	White	Non-Hispanic	28
MNC04	F	R	63	22	White	Non-Hispanic	30
MNC05	F	R	68	17	White	Non-Hispanic	30
MNC06	F	R	68	23	White	Non-Hispanic	28
MNC07	F	R	58	18	White	Non-Hispanic	30
MNC08	M	L	70	18	NR	NR	30
MNC09	M	R	71	27	White	Non-Hispanic	27
MNC10	F	R	70	16	White	Non-Hispanic	28
MNC11	F	R	62	16	White	Non-Hispanic	28
MNC12	M	R	51	19	White	Non-Hispanic	29
MNC13	F	R	73	20	White	Non-Hispanic	26
MNC14	F	R	48	14	White	Non-Hispanic	26
MNC15	F	R	64	18	White	Non-Hispanic	30
MNC16	F	R	47	18	White	Non-Hispanic	29
Mean			61.8	18.5			28.6
SD			8.7	3.2			1.4

Note. *Edu* = Education (yrs); *MoCA* = Montreal Cognitive Assessment (/30);
NR = No Response

Table 8.3 BWA Demographic Characteristics

ID	Sex	Hand	Age	Edu	MPO	Race	Ethnicity	L1	AoA	WAB AQ - ENG	WAB-R Classification - ENG	WAB AQ - SPN	WAB-R Classification -SPN
BWA05	M	R	45	13	112	White	Hispanic	Spanish	21	42.9	Broca's	47.8	Broca's
BWA06	M	R	75	14	54	White	Hispanic	Spanish	8	83.5	Anomic	81.4	Anomic
BWA07	F	R	38	17	41	White	Non- Hispanic	English	19	98	NABW	87.7	Anomic
BWA08	M	R	65	19	52	White	Non- Hispanic	English	21	96	NABW	82.5	Anomic
BWA10	F	R	54	19	138	White	Hispanic	Spanish	18	46.2	Broca's	89	Anomic
BWA11	F	L	27	12	90	White	Hispanic	Spanish	3	65.6	Conduction	40.1	Broca's
BWA12	M	R	69	18	52	White	Hispanic	Spanish	12	50.8	Broca's	39.3	Broca's
BWA13	M	R	80	18	54	White	Non- Hispanic	English	18	57.9	Conduction	49	Wernicke's
Mean			56.6	16.2	74.1				15	67.6		64.6	
SD			18.7	2.8	35.1				6.6	22.1		22.3	

Note. *Edu* = Education (yrs); *MPO* = Months post-onset; *AoA* = L2 Age of Acquisition; *NABW* = Not Aphasic by WAB

Table 8.4 BNC Demographic Characteristics

ID	Sex	Hand	Age	Edu	Race	Ethnicity	L1	AoA	MoCA
BNC01	F	R	24	16	White	Non-Hispanic	English	13	30
BNC02	M	R	29	22	White	Non-Hispanic	Spanish	3	27
BNC03	F	R	24	16	White	Non-Hispanic	English	6	28
BNC04	M	R	72	18	White	Hispanic	Spanish	30	29
BNC06	M	R	48	16	White	Non-Hispanic	Spanish	15	30
BNC07	F	R	43	12	Asian	Hispanic	Spanish	18	26
BNC08	F	R	37	19	White	Non-Hispanic	English	7	30
BNC09	F	R	60	18	White	Non-Hispanic	English	18	30
BNC10	F	R	29	23	White	Hispanic	Spanish	6	30
BNC11	F	R	33	28	White	Hispanic	Spanish	4	25
Mean			39.9	18.8				12.0	28.5
SD			16.0	4.5				8.4	1.9

Note. *Edu* = Education (yrs); *AoA* = L2 Age of Acquisition; *MoCA* = Montreal Cognitive Assessment score (/30)

8.1.2. Eye Tracking

All participants completed an eye tracking experiment across two testing sessions to examine how lexical access and sentence context affect reading comprehension. The experimental task was eye tracking during reading in which participants were instructed to read silently for comprehension while the eye tracker monitored their gaze patterns. This eye tracking during reading design will be described in detail below.

8.1.2.1. Stimuli

The stimuli consisted of 176 English sentences divided into two lists of 88 sentences each. In a 2 x 2 design, participants read 22 experimental and 22 control words embedded in high or low semantically constrained sentences resulting in four conditions across each testing session. Semantic constraint was operationalized as the extent to which sentence context—presented to the left of a target word—biased a reader’s prediction of encountering that target word. In accordance with Aim 2.3, participants read 22 cognate nouns, or words that share orthography and meaning between languages (e.g., *piano*), and 22 frequency and length-matched control nouns (e.g., *pencil*) in both high and low constraint sentences to examine lexical facilitation effects (i.e., faster reading times). Participants also read 22 interlingual homograph nouns, or words that share orthography but diverge in meaning (e.g., *fin* means ‘animal body part’ in English but ‘end’ in Spanish), and 22 frequency and length-matched control nouns in high and low semantic constraint sentences to examine interference effects (i.e., slower reading times). The 88 stimuli in each list were chosen such that sentences containing the same target word were read in two different testing sessions (e.g., a sentence containing the cognate ‘piano’ appeared once in

each list) to minimize practice effects and reduce the possibility that participants discerned patterns in the stimuli. The order of list administration was counterbalanced across participants.

The stimuli were developed by taking existing cognate, homograph, and control words from Schwartz & Kroll (2006) and Schwartz & Areas (2008) and incorporating them into new high and low constraint sentences. Only cognate/control and homograph/control pairs that were nouns in both languages were included to avoid cross-language word class effects (e.g., *dice/dice*; noun in English, verb in Spanish) on sentence processing. Additionally, the Cross-Linguistic Easy-Access Resource for Phonological and Orthographic Neighborhood Density (CLEARPOND; Marian et al., 2012) was used to ensure lexical frequency and orthographic length were matched between the experimental and control word pairs.

All sentences were constructed to be 12 words in length which is an accessible length for PWA based on previous studies that have used eye tracking during reading (DeDe, 2017; DeDe & Kelleher, 2021; Huck et al., 2017a; Knilans & DeDe, 2015). Additionally, all stimuli were simple active sentences designed to diminish possible effects of grammatical processing deficits (i.e., agrammatism) on silent reading comprehension. Each sentence had the same surface phrase structure to further control for word order effects on sentence processing: [prepositional phrase1] [determiner + noun] [verb] [determiner + adjective] [target] [prepositional phrase2]. Under this template, target cognates or homographs and matched control words were always preceded by 8 words and were immediately followed by a prepositional phrase of 3 words. The adjective

immediately preceding the target was at least five letters in length to minimize the probability of skipping the target word. 176 comprehension probes consisting of short questions that targeted one of the noun phrases or the verb phrase in each sentence were also created to gauge attention to the task and general understanding of content. Examples of proposed stimuli and comprehension probes are presented in Table 8.5.

Table 8.5. Example Eye Tracking Stimuli & Probes

Target Word	High Semantic Constraint	Low Semantic Constraint
Cognate	(a) Before the concert, the composer tuned the shiny piano on the stage.	(b) In the morning, the janitor cleaned the shiny piano on the stage.
Cognate Control	(c) Before the quiz, the girl sharpened the expensive pencil by the trash.	(d) In the morning, the boy dropped the expensive pencil by the trash.
Homograph	(e) At the beach, the lifeguard spotted the large fin near the dock.	(f) In the afternoon, the mother saw the large fin near the dock.
Homograph Control	(g) At the pond, the hiker noticed the large frog near the water.	(h) In the afternoon, the girl watched the large frog near the water.
Comprehension Question (a): Did the composer tune the shiny piano? → YES		
Comprehension Question (f): Did the mother see a grey bird? → NO		
Note. Bolded words are frequency and length-matched targets. <i>High Constraint</i> lists high predictability sentence examples. <i>Low Semantic Constraint</i> lists low predictability sentence examples.		

8.1.2.2. Norming

Consistent with previous studies (Libben & Titone, 2009; Schwartz & Kroll, 2006), 20 young neurologically healthy adults (eye tracking norming controls; ENC) were recruited to norm the eye tracking stimuli and verify the semantic constraint manipulation (see Appendix 7 for individual demographics). All 176 sentences were divided into two lists, and each list was administered to 10 ENC. In a semantic judgment task, the participants were directed to read each sentence silently and rate each on a scale from 1-10 where scores 1-5 denoted low constraint or low predictability sentences and scores 6-10 denoted high constraint or high predictability sentences. The instructions were, “Please

read each sentence silently until you encounter a word in bold. Then, provide a rating on a scale from 1-10 based on how likely you think the word in bold was to appear in the sentence based on the preceding words.” Two-way random effects intraclass correlation coefficients (ICCs) for pooled data across the two lists revealed good to excellent consistency and reliability among all 20 raters for labeling high constraint sentences (ICC = 0.89) and low constraint sentences (ICC = 0.85) accurately. The expectation was that within-condition, there would be significant differences in ratings for high vs. low constraint sentences and across-condition there would not be differences in ratings for the same constraint type (e.g., High Cognate vs. High Homograph). As expected, the high and low constraint sentences were perceived differently based on the results of independent samples t-tests (see Table 8.6) within-condition. Additionally, t-tests between-condition revealed no significant differences across word categories which suggests that there was no interaction between constraint and word category (see Table 8.6).

Table 8.6. T-test results for Within- and Between-condition Constraint Judgments

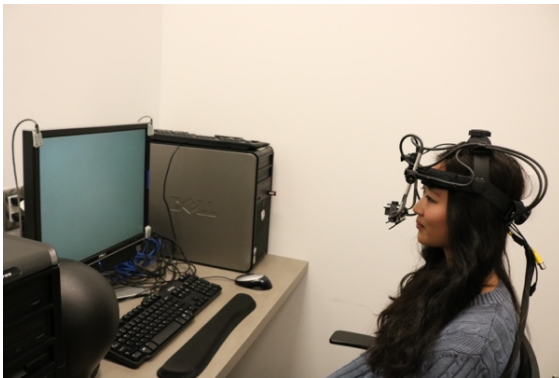
Measure	High Avg	Low Avg	T-value	P-value
Cognate	7.43	3.60	18.95	<.001
Cognate Control	6.73	3.81	14.51	<.001
Homograph	7.32	3.77	18.08	<.001
Homograph Control	6.68	3.62	15.16	<.001
Measure	Cognate Avg	Homograph Avg	T-value	P-value
High Cognate – High Homograph	7.43	7.32	0.58	.561
Low Cognate – Low Homograph	3.60	3.77	-0.75	.450
High Cog Control – High Homo Control	6.73	6.68	0.23	.185
Low Cog Control – Low Homo Control	3.81	3.62	1.04	.297

Note. The first five rows display the results of the within-condition t-tests that show the high vs. low constraint manipulation was perceived similarly across categories. *High Avg/Low Avg* denotes the average rating for all high and low constraint sentences for each measure, respectively. The second five rows display the results of the between-condition t-tests that show no difference in high constraint ratings or low constraint ratings between categories. *Cognate/Homograph Avg* indicates the average rating for all cognate and homograph sentences across each measure, respectively.

8.1.2.3. Procedures

Participants completed the eye tracking sessions in a quiet testing environment in the Center for Brain Recovery at Boston University. During stimuli presentation, participants were seated approximately 50 centimeters from the display screen in a height-adjustable chair. Sentences were presented in black Monaco 14-point font in a single line on a white background. Eye movements were recorded using an EyeLink II eye tracking system (SR Research, Toronto, ON, Canada, 2006) with spatial resolution of 0.02° and a sampling rate of 250 Hz. The eye tracker was composed of three cameras and an adjustable headband that was fitted to the participant's head shape to preserve accurate gaze tracking while allowing for typical head motion. Two PCs interfaced with the eye tracker directly and were responsible for controlling the presentation of stimuli and detecting, monitoring, and analyzing eye gaze in real-time. See Figure 8.1 for eye tracking setup.

Figure 8.1 Eye Tracking Setup



Caption. A demonstration of the eye tracking setup including the adjustable headband, display PC for stimuli presentation, and an example participant seated at the experiment desk.

Prior to data collection, participants passed a screener for visual neglect (the Bells Test; Gauthier et al., 1989) and completed a 3-point calibration procedure (SR Research, 2006) to ensure their eye gaze may be registered by the eye tracker. After successful

calibration, participants completed 4 practice items to orient them to the eye tracking task. Individual trials, including the practice items, were administered in the following manner.

First, a fixation circle appeared at the far-left edge of the screen and participants were instructed to fixate on a small dot in the center of the circle. The circle on the left of the screen ensured that participants started reading at the beginning of the sentence rather than at another point in the sentence and provided examiner control over the pace of the presentation of trials. Once gaze detection was successful, the examiner accepted this first fixation and pressed a button to initialize the trial. Immediately, the entire sentence trial became visible, and participants were instructed to read for comprehension silently. Sentences were visible in their entirety—permitting multiple rereading—until the participant pressed a button to advance the experiment or until 20 seconds had elapsed. Finally, a comprehension question appeared after participants indicated they had finished reading a sentence. Each comprehension question required participants to register their answer via a yes/no button press. Participants were permitted to take breaks between trials upon request; the examiner also provided verbal updates about progress, typically at 50% completion. The need for recalibration was assessed throughout the eye tracking sessions; in general, recalibration occurred after any breaks and whenever the eye tracker failed to detect the participant’s gaze at the left edge of the screen several times in succession.

8.1.3. Design & Data Analysis

8.1.3.1. Eye Tracking Measures

Eye tracking measures for analysis were reported based on eye fixations over the time course of reading. Fixations are defined as the time between rapid eye movements, or

saccades, during which the eyes remain relatively stationary to allow for focused visual processing. During data analysis, fixations at two pre-defined areas of interest (the target word, interest area 5 and the spillover region, interest area 6) were summed to yield four dependent measures: i) first fixation duration, ii) gaze duration, iii) go-past duration, and iv) rereading duration.

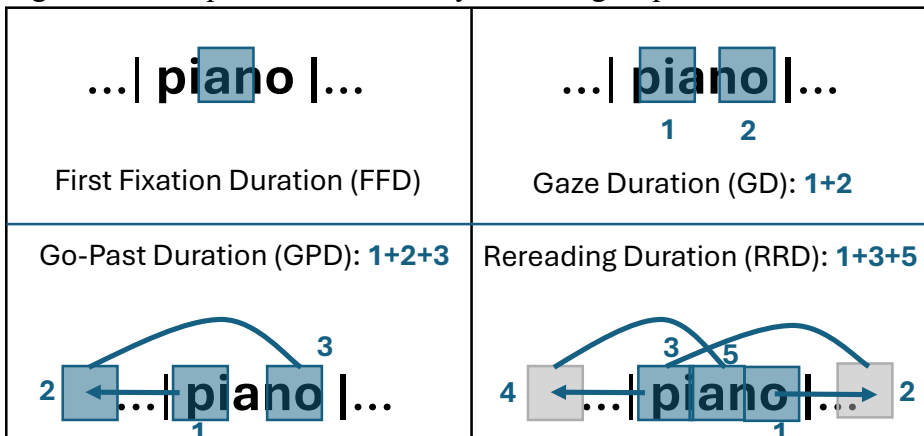
First fixation duration represents the duration of the first time an individual focuses on an area of interest without refixating or moving to the left or the right out of the area. Similarly, gaze duration represents the sum of all first-pass fixations (as opposed to successive pass fixations) in an area of interest before the eyes leave the area and move left or right. Both first fixation duration and gaze duration are thought to index the beginning stages of lexical access and sentence processing and are aptly designated *early-stage processing measures* (Clifton et al., 2007). In contrast to the early-stage measures, *late-stage processing measures* such as go-past time and rereading time are thought to index sentence processing that unfolds in conjunction with successive passes through areas of interest. For example, go-past time which reflects the sum of all fixations from the moment the eyes land on an area of interest until they move to the right—including any regressive eye movements to the left of the area—is thought to signify attempts to integrate new lexical and syntactic information into the unfolding sentence context. Rereading time is the sum of all refixation durations in an area of interest after regressive eye movements (i.e., not refixations included in gaze duration). The relationships between reading behavior and these dependent measures are summarized below and illustrated using the example

(b) In₂ the₃ morning_{1,9} the janitor₄ cleaned₅ the shiny_{6,10} piano_{7,8,11,13} on the stage_{12,14}.

sentence (b) from Table 8.5.

The subscripts in (b) represent potential fixations during reading. In this example, an individual began reading at the leftmost word of the sentence, but the first fixation occurred three words in—at ‘morning’. The next fixations (2, 3) were the result of regressions—or backwards eye movements to an earlier part of the sentence. After some forward fixations in 4-6, the individual eventually reached the target cognate in the sentence at 7 which constituted the **first fixation duration** for ‘piano’ as this was the first time the individual focused on the word. Fixation 8 represents a re-fixation—that is—the individual perhaps focused on the ‘p’ in the first half of ‘piano’ during 7 and the ‘o’ during 8 without moving their eyes into a different area of interest. Together, the sum of fixations 7 and 8 constitute the **gaze duration** for ‘piano’. The remaining fixations constitute a combination of regressive and forward parsing behaviors that demonstrate the depth and complexity of reading behaviors that may be captured within one trial. For example, the sum of fixations 7-11 represent the **go-past time** which is the time it takes the individual to read beyond ‘piano’ (including regressive movements to the left of piano) and the sum of 11 and 13 represent the **total rereading time**, comprised of regressions back in to ‘piano’ after reading another word to the right or left. Finally, it should be noted that several words such as ‘the’, ‘in’, and ‘of’ were skipped during the reading of (b). This skipping behavior is typical during normal sentence reading and is more likely to happen for short or function words (Drieghe et al., 2005; Rayner, 1998). A schematic emphasizing the differences between the four dependent measures is shown in Figure 8.2 for the same target word, ‘piano’.

Figure 8.2 Comparisons between Eye Tracking Dependent Measures



Caption. Visual schematic illustrating how different eye-tracking measures are derived from the same fixation sequence at a single target word during sentence reading. Each panel depicts the same sentence context with the target word in bold and ‘...’ to show words that precede and follow the target. Fixation boxes and arrows indicate the order and direction of eye movements. Panels differ only in which fixations are included in the calculation, demonstrating how first-fixation duration, gaze duration, go-past duration, and rereading duration are distinguished across the timecourse of processing.

8.1.3.2. Areas of Interest

The measures are presented in reading times for the target word in (b); however, multiple words/regions of the sentences were investigated as indices of cognitive processing during reading. These areas visible in (b) below are: [prepositional phrase1] [determiner + noun] [verb] [determiner + adjective] [prepositional phrase2].

General predictions for the cognate and homograph stimuli focused on comparing reading times at the target word across stimuli. In the cognate experiment, the bilingual groups were expected to show faster reading times for cognate words vs. control words given that cognates have one semantic representation in the bilingual lexicon and do not incur a processing cost when integrating their meaning into the unfolding sentence context. However, sensitivity to this difference in reading times was predicted to vary across

semantic constraint and early vs. late-stage measures for both groups. A similar pattern of behavior was expected for the homograph stimuli. There, the bilingual groups were hypothesized to show longer reading times across measures for homographs vs. control words because reading a homograph activates two competing semantic representations and one must be inhibited to comprehend the sentence context. Again, these effects were expected to be modulated by factors including group, semantic constraint, and eye tracking measure.

There are no specific predictions about behavior at the other areas of interest in the sentences; nevertheless, reading time measures were also calculated for area 6, or the spillover area, for potential evidence of delayed facilitation or interference in BWA relative to the BNC. For example, some participants may not show immediate effects of longer reading times at a target homograph word but may show exaggerated fixations at the prepositional phrase immediately following the target area. These potential spillover effects may be vital indices of processing disruptions that appeared past the predicted target area because individuals with aphasia often show delays in lexical integration and overall sentence processing.

8.1.3.3. Data Preprocessing

The eye tracking experiment was implemented using Experiment Builder (SR Research, 2024) and data files were opened and processed with Data Viewer (SR Research, 2025). After the experiment was completed, each list file was imported to Data Viewer for (pre)processing. First, practice trials were excluded prior to analysis as were trials in which participants did not provide a button-press response for comprehension accuracy. Then,

trials were excluded in which participants blinked in the target area of interest (area 5) during first pass reading of the target. Then, all fixations which occurred in a part of the screen not covered by an area of interest were removed to avoid the program summing these with fixations in the nearest area of interest. Two list-level files were then generated for each participant that included the dependent measures above (or the variables to compute them, e.g., rereading time) by area of interest and trial-level accuracy on the comprehension probes.

8.1.4. Statistical Analyses and Rationale

Like in Aim 1, a mixed-effects modeling approach was adopted across the research questions in Aim 2. This approach was selected because the behavioral assessment data consisted of trial-level accuracy from multiple tasks with repeated observations nested within participants and stimuli (Baayen et al., 2008; Jaeger, 2008). Linear mixed-effects models (LMMs) and GLMMs were therefore used to estimate reading durations across various eye tracking measures or the probability of a correct response to a comprehension probe, respectively, as a function of fixed predictors and random effects for participants.

8.1.4.1. Aim 2.1

Sentence-level comprehension accuracy and total sentence reading time analyses were conducted on sentence-level data in which interest-area-level observations were collapsed.

Comprehension accuracy was analyzed using a logistic regression model, and total sentence reading time was analyzed using a linear model fit to log-transformed reaction times. For both outcomes, fixed effects included group (BWA, BNC, MWA, and MNC),

semantic constraint (high vs. low), and their interaction. Semantic constraint was sum-coded to estimate effects averaged across sentence types, and BWA served as the reference group for the group variable. The BWA were selected as the reference group to facilitate direct interpretation of model coefficients as differences relative to the BWA, the primary population of interest in Aim 2. This choice affected coefficient interpretation but did not affect model fit or statistical inferences. Random intercepts were included for participants and sentences. Effects are reported in log-odds for comprehension accuracy and log-transformed milliseconds for sentence reading time with exponentiated estimates used to facilitate interpretation of group differences in reading behavior. Post-hoc comparisons for differences in accuracy and reading times were planned a priori for MWA vs. MNC as the default coding of the model did not already contain this comparison of interest.

8.1.4.2. Aim 2.2

Aim 2.2 examined fine-grained reading time measures at the interest-area level to characterize early- and late-stages of sentence processing in monolingual and bilingual readers with and without aphasia. Analyses focused on two interest areas which were selected to capture processing at—and immediately following—the target region of the sentence.

Four standard eye-tracking measures were analyzed: first fixation duration, gaze duration, go-past duration, and rereading duration. All measures were computed at the interest-area level and log-transformed by taking the natural logarithm of the reading time measure prior to analysis to reduce positive skew and improve model fit. Separate linear mixed-effects models were fit for each measure and interest area. To facilitate targeted

group comparisons, monolingual (MWA vs. MNC) and bilingual (BWA vs. BNC) participants were analyzed in separate model sets. Within each set, fixed effects included group, semantic constraint (high vs. low), and their interaction. Group was treatment-coded with the neurologically healthy group (MNC or BNC) serving as the reference level to observe direct deviations in reading times for the aphasia group, and constraint was sum-coded to reflect the mean difference between high and low semantic conditions. Random intercepts for participant were included in all models to account for repeated observations within individuals. Random intercepts for item contributed too little variance to the model estimates and were removed before final analysis. To address multiplicity across parallel models fit to different eye-movement measures, p-values for the group \times constraint interaction were planned to be adjusted within each interest area using FDR correction across the four measures (FFD, GD, GPD, RRD). IA 5 and IA 6 were treated as separate families.

8.1.4.3. Aim 2.3

Aim 2.3 investigated cognate and homograph effects and their potential interactions with semantic constraint on the same reading measures used in Aim 2.2. Since this Aim focused on bilingual processing, these lexical effects were evaluated only for the bilingual groups as the cognate and homograph manipulations were not meaningful for the monolingual groups. A series of linear mixed effects models were fit to analyze these relationships that were composed of fixed effects of group (BWA vs. BNC), stimulus type (cognate vs. cognate control words and separately homographs vs. homograph control words), and constraint (high vs. low), and their three-way interaction. Group was

treatment-coded with BNC serving as the reference level while stimulus type and constraint were both sum-coded to reflect the mean across both levels of their variable structure. As in Aim 2.2, random effects only included an intercept for participant. To address multiplicity across parallel models fit to different eye-movement measures, p-values for the group \times constraint \times target word interaction were planned to be adjusted within each interest area and cognate/homograph models using FDR correction across the four measures (FFD, GD, GPD, RRD).

8.2. Results

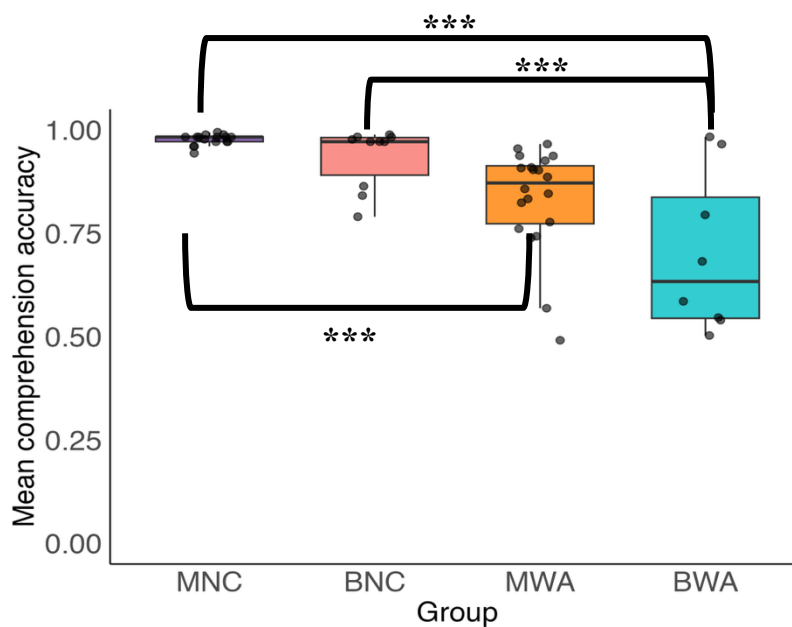
8.2.1. Aim 2.1

Sentence-level comprehension accuracy and total sentence reading time were analyzed using mixed-effects models with group and semantic constraint as fixed effects (and their interaction) and random intercepts for participants and sentences. In both models, BWA served as the reference group since comparisons between this group and the other three would be produced automatically based on treatment coding. Semantic constraint was sum-coded such that main effects reflected averages across high- and low-constraint sentences.

For comprehension accuracy (see Figure 8.3), a mixed-effects logistic regression revealed a significant main effect of group (see Table 8.7). Relative to BWA, BNC showed significantly greater likelihood of a correct response on a comprehension probe ($b = 2.07$, $SE = 0.48$, $z = 4.28$, $p < .001$), as did MNC ($b = 2.93$, $SE = 0.44$, $z = 6.53$, $p < .001$). In contrast, MWA did not differ significantly from BWA ($b = 0.69$, $SE = 0.41$, $z = 1.66$, $p =$

.090). A planned post hoc contrast showed that the MWA had significantly lower sentence-level comprehension accuracy than MNC ($b = -2.08$, $SE = 0.49$, $z = -4.29$, $p < .001$). There was no main effect of semantic constraint on comprehension accuracy ($b = -0.06$, $SE = 0.16$, $z = -0.39$, $p = .68$), and none of the group \times constraint interactions reached significance.

Figure 8.3. Comprehension Probe Accuracy by Group

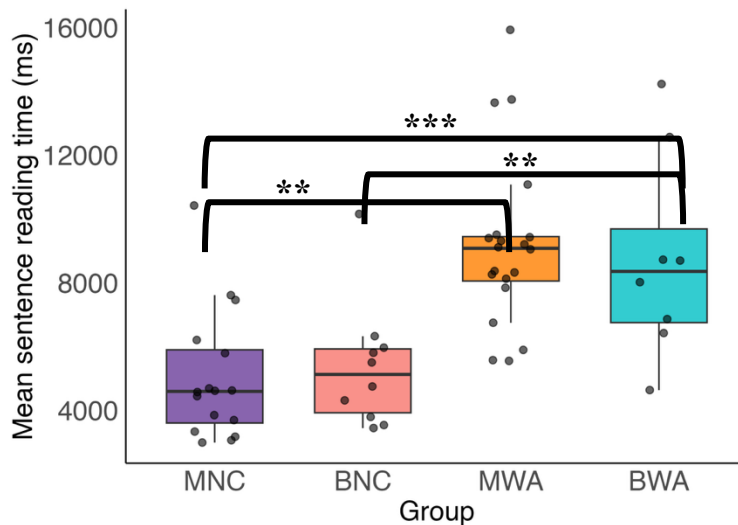


Caption. Mean accuracy across comprehension probes is shown by group. Individual points represent participant-level accuracy within group. The likelihood of a correct response on a comprehension probe was significantly lower for BWA relative to both neurological control groups, but not to the MWA. MWA were significantly less likely to answer correct when compared to MNC. Brackets indicate comparisons of interest. Significance stars indicate the p-value: * = $p < .05$, ** = $p < .01$, *** = $p < .001$.

Total sentence reading time (see Figure 8.4) was analyzed using a linear mixed-effects model fit to log-transformed reaction times (see Table 8.7). Consistent with the accuracy results, there was a robust main effect of group. Both BNC and MNC read sentences significantly faster than BWA (BNC: $b = -0.48$, $SE = 0.15$, $t = -3.13$, $p = .002$;

MNC: $b = -0.56$, $SE = 0.14$, $t = -3.97$, $p < .001$). By contrast, the MWA did not differ reliably from BWA in sentence reading time ($b = 0.06$, $SE = 0.13$, $t = 0.48$, $p = .62$). A planned post hoc contrast showed that the MWA read sentences significantly slower than the MNC ($b = 0.49$, $SE = 0.16$, $z = 3.14$, $p = .001$). As with comprehension accuracy, there was no main effect of semantic constraint on sentence reading time ($b = -0.01$, $SE = 0.02$, $t = -0.50$, $p = .61$), and no evidence that the effect of constraint differed across groups.

Figure 8.4. Total Sentence Reading Times by Group



Caption. Mean sentence reading times across groups are shown. Individual points represent participant-level reading times. BWA spent much longer reading sentences relative to both neurological control groups, but not relative to the MWA. The MWA also took significantly longer to read sentences when compared to the MNC. Brackets indicate comparisons of interest. Significance stars indicate the p-value: * = $p < .05$, ** = $p < .01$, *** = $p < .001$.

Table 8.7. Aim 2.1: Comprehension Accuracy and Total Sentence Reading Models

Data	Effect	Term	Estimate	SE	Z/t	p-value
Binary Comp. Acc	Fixed	Intercept	1.27	0.35	3.57	< .001
	Fixed	GroupBNC	2.07	0.48	4.28	< .001
	Fixed	GroupMNC	2.93	0.44	6.53	< .001
	Fixed	GroupMWA	0.69	0.41	1.66	.09
	Fixed	Constraint (Sum-coded)	-0.06	0.16	-0.39	.68
	Fixed	GroupBNC:Constraint	-0.05	0.24	-0.22	.82
	Fixed	GroupMNC:Constraint	-0.19	0.28	-0.66	.5
	Fixed	GroupMWA:Constraint	0.31	0.16	1.83	.06
	Random	Item (SD)	0.66			
	Random	Participant (SD)	0.96			
Log Sentence Reading Time	Fixed	Intercept	9.02	0.11	77.7	< .001
	Fixed	GroupBNC	-0.48	0.15	-3.13	< .01
	Fixed	GroupMNC	-0.56	0.14	-3.97	< .001
	Fixed	GroupMWA	0.06	0.13	0.48	.62
	Fixed	Constraint (Sum-coded)	-0.01	0.02	-0.5	.61
	Fixed	GroupBNC:Constraint	0.02	0.02	0.88	.37
	Fixed	GroupMNC:Constraint	0	0.02	0.1	.91
	Fixed	GroupMWA:Constraint	-0.01	0.02	-0.94	.34
	Random	Item (SD)	0.09			
	Random	Participant (SD)	0.32			

Note. *SE* = Standard Error; *Z/t* = z-statistic, reported for accuracy model and t-statistic reported for reading time model; *SD* = Standard Deviation

8.2.2. Aim 2.2

Appendices 8 and 9 provide an overview of reading time distributions across early-stage measures, including first fixation duration and gaze duration, and late-stage measures, including go-past duration and rereading duration, for the monolingual and bilingual participants. The figures contain panels to demonstrate patterns across interest areas 5 (e.g., the target word) and 6 (e.g., spillover prepositional phrase region) and the high- and low-constraint sentences. These figures were intended to illustrate overall patterns of variability across the groups; statistical inferences are based on the mixed-effects models reported below.

8.2.2.1. *Monolingual Performance*

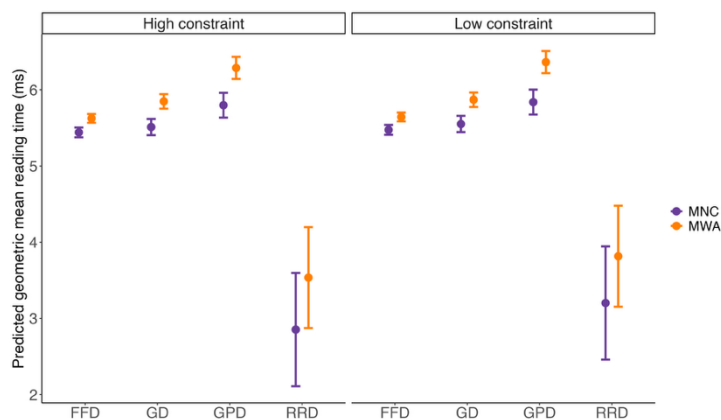
Across both interest areas, MWA exhibited consistently longer reading times than MNC across early- and late-stage processing measures (Figure 8.5; Table 8.8). No group \times semantic constraint interactions reached significance for any measure or region, indicating that group differences reflected generalized slowing rather than differential sensitivity to semantic constraint. Therefore, no correction for multiple comparisons was performed. Instead, main effects of group and semantic constraint emerged independently across stages of processing.

At the target region (interest area 5), early-stage measures showed parallel effects of group and semantic constraint. First fixation duration and gaze duration were significantly longer in MWA than in MNC (FFD: $b = 0.18$, $p < .01$; GD: $b = 0.33$, $p < .001$), indicating slowed early lexical access in aphasia. Collapsing across groups, both measures were also longer for low-constraint sentences (FFD: $b = 0.03$, $p = .01$; GD: $b = 0.04$, $p =$

.02), demonstrating sensitivity to semantic constraint at the earliest stages of processing in both groups. The absence of group \times constraint interactions across early measures indicates that this constraint sensitivity was comparable for MWA and MNC despite overall group-level slowing.

Later-stage measures at the target region revealed a more differentiated pattern (see Figure 8.5; Table 8.8). Go-past duration remained significantly longer in MWA than in MNC ($b = 0.48, p < .001$), reflecting greater difficulty integrating the target word and moving forward in the sentence. However, semantic constraint no longer influenced go-past duration ($p = .22$), suggesting that constraint effects were transient during initial integration. In contrast, rereading duration did not differ reliably by group ($p = .18$) but showed a robust main effect of constraint ($b = 0.34, p < .01$), with greater rereading in low-constraint sentences across both groups. Together, these results indicate that at the target word, semantic constraint exerts its strongest influence during early lexical access, wanes during initial integration, and re-emerges selectively during later rereading.

Figure 8.5 Model Predicted Reading Times for Monolinguals at IA 5



Caption. Model-predicted geometric mean reading times ($\pm 95\%$ confidence intervals) for first fixation duration (FFD), gaze duration (GD), go-past duration (GPD), and rereading duration (RRD) at the target region (Interest Area 5) in monolingual participants. Estimates

are shown separately for high- and low-constraint sentences and are derived from log-transformed linear mixed-effects models. Points represent estimated marginal means; error bars indicate 95% confidence intervals. Values on the y-axis represent geometric mean reading times in milliseconds, obtained by exponentiating model estimates from log-transformed outcomes.

Table 8.8. Aim 2.2: Monolingual Group x Constraint & Reading Measures Models

Data	Effect	Term	Estimate	SE	t	p-value
FFD (IA 5)	Fixed	Intercept	5.44	0.03	165.25	< .001
	Fixed	Group (MWA vs. MNC)	0.18	0.04	4.17	< .01
	Fixed	Constraint (low vs. high)	0.03	0.01	2.38	0.01
	Fixed	Group x Constraint	-0.01	0.01	-0.82	.40
	Random	Participant (SD)	0.01			
GD (IA 5)	Fixed	Intercept	5.51	0.05	101.32	< .001
	Fixed	Group (MWA vs. MNC)	0.33	0.07	4.63	< .001
	Fixed	Constraint (low vs. high)	0.04	0.01	2.23	0.02
	Fixed	Group x Constraint	-0.01	0.02	-0.8	.42
	Random	Participant (SD)	0.04			
GPD (IA 5)	Fixed	Intercept	5.79	0.08	69.69	< .001
	Fixed	Group (MWA vs. MNC)	0.48	0.11	4.39	< .001
	Fixed	Constraint (low vs. high)	0.04	0.03	1.21	.22
	Fixed	Group x Constraint	0.03	0.04	0.81	.41
	Random	Participant (SD)	0.10			
RRD (IA 5)	Fixed	Intercept	2.85	0.37	7.52	< .001
	Fixed	Group (MWA vs. MNC)	0.68	0.5	1.34	.18
	Fixed	Constraint (low vs. high)	0.34	0.12	2.9	< .01
	Fixed	Group x Constraint	-0.06	0.15	-0.43	.66
	Random	Participant (SD)	2.17			
FFD (IA 6)	Fixed	Intercept	5.48	0.03	153.51	< .001
	Fixed	Group (MWA vs. MNC)	0.13	0.04	2.86	< .01
	Fixed	Constraint (low vs. high)	0	0.01	0.31	.75
	Fixed	Group x Constraint	-0.01	0.01	-1.06	.28
	Random	Participant (SD)	0.01			
GD (IA 6)	Fixed	Intercept	5.96	0.08	69.94	< .001
	Fixed	Group (MWA vs. MNC)	0.45	0.11	3.96	< .001

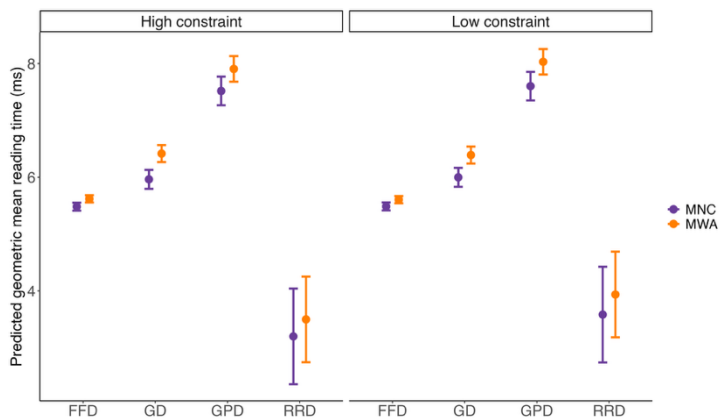
	Fixed	Constraint (low vs. high)	0.03	0.02	1.51	.12
	Fixed	Group x Constraint	-0.06	0.03	-1.93	.05
	Random	Participant (SD)	0.11			
GPD (IA 6)	Fixed	Intercept	7.51	0.12	58.58	< .001
	Fixed	Group (MWA vs. MNC)	0.38	0.17	2.25	.03
	Fixed	Constraint (low vs. high)	0.08	0.02	3.94	< .001
	Fixed	Group x Constraint	0.04	0.02	1.37	.16
	Random	Participant (SD)	0.25			
RRD (IA 6)	Fixed	Intercept	3.19	0.42	7.44	< .001
	Fixed	Group (MWA vs. MNC)	0.29	0.57	0.51	.60
	Fixed	Constraint (low vs. high)	0.38	0.1	3.51	< .001
	Fixed	Group x Constraint	0.05	0.14	0.36	.71
	Random	Participant (SD)	2.85			

Note. *FFD* = First fixation duration; *GD* = Gaze duration; *GPD* = Go-past duration; *RRD* = Rereading duration; *IA* = Interest area; *SE* = Standard Error; *t* = t-statistic; *SD* = Standard Deviation

At the spillover region (interest area 6), group differences persisted for early-stage measures, whereas constraint effects were reduced (see Figure 8.6; Table 8.8). First fixation duration and gaze duration were again longer in MWA than in MNC (FFD: $b = 0.13$, $p < .01$; GD: $b = 0.45$, $p < .001$), indicating continued slowing in first-pass processing beyond the target word (Figure 8.6). In contrast to IA5, neither early-stage measure showed a reliable main effect of semantic constraint at this downstream position ($ps > .10$).

Later-stage measures at the spillover region further reflected this dissociation (see Figure 8.6; Table 8.8). Go-past duration was significantly longer in MWA than in MNC ($b = 0.38$, $p = .03$), consistent with ongoing integration difficulty in aphasia, and showed a strong main effect of semantic constraint ($b = 0.08$, $p < .001$). Rereading duration again did not differ by group ($p = .60$) but exhibited a robust constraint effect ($b = 0.38$, $p < .001$), with greater rereading in low-constraint sentences across both groups. As at the target region, the absence of interactions indicates parallel constraint-driven rereading behavior despite overall group-level slowing.

Figure 8.6 Model Predicted Reading Times for Monolinguals at IA 6



Caption. Model-predicted geometric mean reading times ($\pm 95\%$ confidence intervals) for first fixation duration (FFD), gaze duration (GD), go-past duration (GPD), and rereading duration (RRD) at the spillover region (Interest Area 6) in monolingual participants.

Estimates are shown separately for high- and low-constraint sentences and are derived from log-transformed linear mixed-effects models. Points represent estimated marginal means; error bars indicate 95% confidence intervals. Values on the y-axis represent geometric mean reading times in milliseconds, obtained by exponentiating model estimates from log-transformed outcomes.

In summary, MWA demonstrated widespread slowing across both early and late stages of sentence processing. Semantic constraint effects were most evident during early lexical access at the target word and during later rereading at both the target and spillover regions. Crucially, the absence of group \times constraint interactions across all measures indicates that aphasia was associated with slowed processing rather than altered use of semantic context during sentence reading.

8.2.2.2. Bilingual Performance

In contrast to the monolingual comparisons, bilingual group differences were more restricted and emerged primarily in later-stage processing measures (see Table 8.9). Leaving aside the issue of small sample sizes, one reason for the later-emerging bilingual differences could be due to bilingualism-specific mechanisms. Principally, bilinguals retrieve both word representations as the sentence context unfolds and must inhibit one meaning in Spanish to comprehend the sentences in English. This ongoing process of activation and inhibition could have delayed the timing-related effects relative to the results demonstrated by the MWA. Notably, results at the target region (interest area 5) diverged from the hypotheses outlined in Chapter 6. Contrary to predictions, there were no significant effects of group, semantic constraint, or their interaction for any early- or late-stage measure at this region.

One possible explanation for the absence of effects at the target region is limited statistical power, as the bilingual aphasia sample is smaller at this stage of recruitment. However, this account alone is unlikely to fully explain the pattern, given the consistency of null effects across all four measures at IA5. A more theoretically motivated explanation is that sentence-level reading in bilinguals reflects the interaction of multiple, potentially competing lexical influences that are not explicitly modeled in Aim 2.2. In particular, the sentences used in this experiment contain bilingual lexical items (e.g., cognates and homographs) that are known to facilitate or interfere with word recognition in opposite directions. When these opposing influences are averaged across trials and modeled without reference to lexical status, facilitative and inhibitory effects may cancel out, yielding null effects at the target region despite underlying sensitivity to sentence context. This interpretation is consistent with bilingual interactive activation accounts, which predict that lexical-level effects can modulate or obscure sentence-level effects when not modeled explicitly.

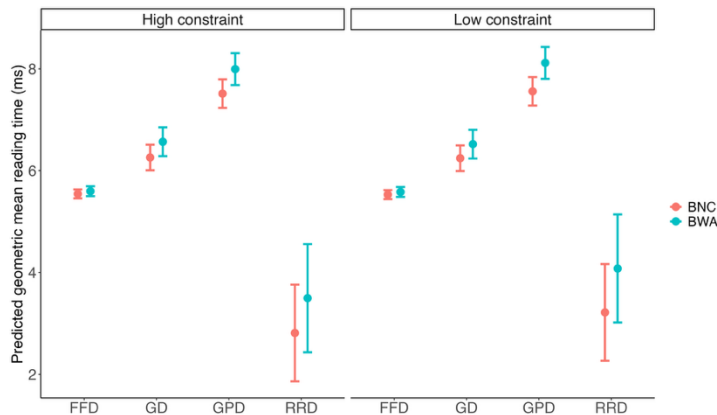
At the spillover region (interest area 6; see Figure 8.7), bilingual group differences emerged in a pattern that closely mirrored the monolingual results. Early-stage measures again showed no reliable effects of group or constraint, indicating comparable first-pass processing in BWA and BNC at this downstream position. In contrast, late-stage measures revealed selective group and constraint effects. Go-past duration was significantly longer in BWA than in BNC, reflecting increased difficulty integrating sentence meaning beyond the target word (see Table 8.9). Rereading duration did not differ by group but was greater for low-constraint sentences across both groups, indicating increased reanalysis when

contextual support was reduced. Given that these later-stage results were comparable across MWA and BWA, it suggests that aphasia caused timing-related differences in processing. However, in future analyses, if the patterns of BWA and MWA are directly compared to one another and there is a difference in timing, it could also suggest that bilingualism is a modulating factor (i.e., BWA are even more delayed than the MWA).

Importantly, the pattern observed at interest area 6 parallels that seen in monolingual adults with aphasia, where group differences were most evident in go-past duration and semantic constraint effects emerged reliably in rereading duration. Together, these findings suggest that in bilingual aphasia, disruptions to sentence processing may be more likely to manifest as delayed integration and rereading difficulty rather than as immediate effects at the target word. This delayed emergence of effects is consistent with the hypothesis that bilingual lexical dynamics modulate early processing, with sentence-level disruptions becoming more apparent downstream once integration demands increase.

Overall, the bilingual results indicate that aphasia-related effects on sentence reading are more selective than in monolinguals and are most evident at later stages of processing and at the spillover region. The absence of target-region effects underscores the importance of explicitly modeling bilingual lexical properties—an issue addressed directly in Aim 2.3—to disentangle facilitative and inhibitory influences on real-time sentence comprehension in bilingual readers.

Figure 8.7 Model Predicted Reading Times for Bilinguals at IA 6



Caption. Model-predicted geometric mean reading times ($\pm 95\%$ confidence intervals) for first fixation duration (FFD), gaze duration (GD), go-past duration (GPD), and rereading duration (RRD) at the spillover region (Interest Area 6) in bilingual participants. Estimates are shown separately for high- and low-constraint sentences and are derived from log-transformed linear mixed-effects models. Points represent estimated marginal means; error bars indicate 95% confidence intervals. Values on the y-axis represent geometric mean reading times in milliseconds, obtained by exponentiating model estimates from log-transformed outcomes.

Table 8.9. Aim 2.2: Bilingual Group X Constraint & Reading Measures Models

Data	Effect	Term	Estimate	SE	t	p-value
FFD (IA 5)	Fixed	Intercept	5.47	0.05	106.4	< .001
	Fixed	Group (BWA vs. BNC)	0.11	0.07	1.52	0.14
	Fixed	Constraint (low vs. high)	0	0.01	0.2	0.83
	Fixed	Group x Constraint	0	0.02	0.4	0.68
	Random	Participant (SD)	0.02			
GD (IA 5)	Fixed	Intercept	5.62	0.08	66.09	< .001
	Fixed	Group (BWA vs. BNC)	0.16	0.12	1.26	0.22
	Fixed	Constraint (low vs. high)	0	0.02	-0.1	0.91
	Fixed	Group x Constraint	0.04	0.03	1.37	0.17
	Random	Participant (SD)	0.06			
GPD (IA 5)	Fixed	Intercept	5.86	0.11	53.11	< .001
	Fixed	Group (BWA vs. BNC)	0.20	0.16	1.21	0.24
	Fixed	Constraint (low vs. high)	0.06	0.03	1.66	0.09
	Fixed	Group x Constraint	-0.03	0.05	-0.55	0.57
	Random	Participant (SD)	0.11			
RRD (IA 5)	Fixed	Intercept	2.77	0.44	6.24	< .001
	Fixed	Group (BWA vs. BNC)	0.85	0.66	1.28	0.21
	Fixed	Constraint (low vs. high)	0.11	0.15	0.79	0.42
	Fixed	Group x Constraint	0.16	0.22	0.75	0.45
	Random	Participant (SD)	1.85			
FFD (IA 6)	Fixed	Intercept	5.54	0.04	133.64	< .001
	Fixed	Group (BWA vs. BNC)	0.05	0.06	0.84	0.4
	Fixed	Constraint (low vs. high)	-0.01	0.01	-0.85	0.39
	Fixed	Group x Constraint	0	0.02	-0.02	0.97
	Random	Participant (SD)	0.01			
GD (IA 6)	Fixed	Intercept	6.25	0.11	52.45	< .001
	Fixed	Group (BWA vs. BNC)	0.30	0.17	1.72	0.1

	Fixed	Constraint (low vs. high)	-0.01	0.03	-0.45	0.65
	Fixed	Group x Constraint	-0.03	0.04	-0.72	0.46
	Random	Participant (SD)	0.13			
	Fixed	Intercept	7.51	0.13	56.66	< .001
	Fixed	Group (BWA vs. BNC)	0.48	0.19	2.41	0.02
GPD (IA 6)	Fixed	Constraint (low vs. high)	0.04	0.03	1.39	0.16
	Fixed	Group x Constraint	0.07	0.04	1.64	0.09
	Random	Participant (SD)	0.17			
	Fixed	Intercept	2.81	0.44	6.24	< .001
RRD (IA 6)	Fixed	Group (BWA vs. BNC)	0.68	0.67	1.01	0.32
	Fixed	Constraint (low vs. high)	0.40	0.15	2.64	< .01
	Fixed	Group x Constraint	0.17	0.22	0.77	0.43
	Random	Participant (SD)	1.90			

Note. *FFD* = First fixation duration; *GD* = Gaze duration; *GPD* = Go-past duration; *RRD* = Rereading duration; *IA* = Interest area; *SE* = Standard Error; *t* = t-statistic; *SD* = Standard Deviation

8.2.3. Aim 2.3

8.2.3.1. *Cognate Facilitation Effects*

Cognate facilitation effects were examined at the target region (interest area 5) and the spillover region (interest area 6) to assess whether bilingual lexical overlap modulated sentence reading as a function of group, semantic constraint, and processing stage. As outlined in Chapter 6 (see Figure 6.2), cognate facilitation was predicted to vary across groups and to interact with semantic constraint over time. Specifically, BNC were expected to show early cognate facilitation during first-pass processing, with facilitation persisting primarily under low-constraint conditions in later measures as contextual support reduced reliance on lexical overlap. For BWA, cognate facilitation was predicted to be exaggerated, delayed, and more persistent across the sentence, reflecting increased reliance on lexical-level support and reduced efficiency in integrating contextual information. These hypotheses did not assume equivalent effects across groups, but rather predicted asymmetries in the timing and magnitude of facilitation.

At the target region (interest area 5; see Table 8.10), there was no reliable evidence that cognate status influenced early first-pass processing. Neither first fixation duration nor gaze duration showed main effects of stimulus type or interactions with group, indicating that cognates did not modulate initial lexical access at the target word. The only early-stage effect at this region was a main effect of semantic constraint in gaze duration, with longer gaze durations observed under low-constraint contexts across groups ($b = -0.06$, $SE = 0.03$, $t = -2.01$, $p = .04$). A similar constraint effect was observed for go-past duration, again reflecting longer reading times in low-constraint sentences regardless of group or stimulus

type ($b = -0.10$, $SE = 0.05$, $t = -2.01$, $p = .04$).

By contrast, later reanalysis at the target region showed selective sensitivity to cognate status across groups. Rereading duration revealed a significant constraint-by-stimulus interaction ($b = -1.08$, $SE = 0.41$, $t = -2.62$, $p < .001$), such that cognates elicited reduced rereading in high-constraint sentences, with this facilitation attenuated under low constraint (see Appendix 10). This effect did not differ between BWA and BNC, indicating that cognate status modulated later-stage processing similarly in both groups when semantic context supported integration. Together, the target-region results suggest that cognate facilitation does not operate during initial access, but instead emerges during later reanalysis when sentence context can be leveraged to support meaning integration.

At the spillover region (interest area 6), early-stage measures again showed no reliable effects of group, stimulus type, or constraint. First fixation duration and gaze duration did not reveal evidence of cognate facilitation during first-pass processing beyond the target word. By contrast, later-stage measures revealed clearer patterns. Go-past duration was significantly longer in BWA than BNC ($b = 0.52$, $SE = 0.19$, $t = 2.65$, $p = .01$), indicating greater downstream integration difficulty for the aphasia group. Independent main effects of semantic constraint ($b = -0.08$, $SE = 0.04$, $t = -2.00$, $p = .04$) and stimulus type ($b = -0.11$, $SE = 0.04$, $t = -2.50$, $p = .01$) further showed that low-constraint contexts increased processing time overall, while cognates facilitated processing relative to control words. These effects were qualified by a constraint-by-stimulus interaction ($b = -0.18$, $SE = 0.08$, $t = -2.10$, $p = .03$), indicating that cognate facilitation in go-past duration was strongest under high semantic constraint and diminished under low

constraint. For rereading duration at interest area 6, a main effect of constraint again emerged ($b = -0.48$, $SE = 0.21$, $t = -2.25$, $p = .02$), reflecting increased rereading in low-constraint sentences across groups, with no reliable modulation by cognate status or group. Given the null effects for the three way-interaction across IA5 and IA6, no multiple comparison corrections were performed.

Taken together, the cognate facilitation results only partially supported the predictions outlined in Chapter 6. Contrary to expectations, cognate status did not reliably influence early first-pass processing at either the target or spillover region for either group, suggesting that lexical overlap alone was insufficient to modulate initial access once sentence context was present. Instead, cognate effects emerged selectively during later stages of processing and were strongly contingent on semantic constraint. At the target region, facilitation was observed only in rereading duration and only under high-constraint conditions, consistent with the idea that contextual support enables more efficient reanalysis when lexical representations overlap. At the spillover region, late-stage processing again showed sensitivity to cognate status, with facilitation strongest under high constraint and attenuated under low constraint, alongside overall slowing for the BWA group. Importantly, these effects were delayed rather than persistent and did not extend uniformly across measures or regions. This pattern suggests that cognate facilitation during sentence reading operates primarily at the level of integration and reanalysis, rather than during initial lexical access, and that its expression is tightly coupled to semantic context. The absence of robust early facilitation effects, particularly at the target region, runs counter to the original predictions in Chapter 6. However, these results are consistent with

patterns observed in Aim 2.2, where sentence-level analyses that did not model bilingual lexical properties yielded attenuated or null effects. Together, these findings suggest that competing influences of bilingual lexical activation and sentence-level processing demands can obscure effects at individual sentence regions unless lexical status and constraint are accounted for together in bilingual populations.

Table 8.10. Aim 2.3: Cognate Models by Constraint and Interest Area

Data	Effect	Term	Estimate	SE	t	p-value
FFD Cog (IA 5)	Fixed	Intercept	5.46	0.04	111.83	< .001
	Fixed	Group (BWA vs. BNC)	0.12	0.07	1.68	.11
	Fixed	Constraint (high vs. low)	-0.02	0.02	-1.19	.23
	Fixed	Stimulus Type (cog vs. control)	0.02	0.02	0.95	.33
	Fixed	GroupBWA:Constraint	0	0.03	0.15	.87
	Fixed	GroupBWA:Stimulus Type	-0.01	0.03	-0.39	.69
	Fixed	Constraint:Stimulus Type	0	0.04	-0.01	.98
	Fixed	GroupBWA:Constraintc:Stimulus	-0.01	0.06	-0.3	.76
	Random	Participant (SD)	0.02			
GD Cog (IA 5)	Fixed	Intercept	5.64	0.08	62.91	< .001
	Fixed	Group (BWA vs. BNC)	0.18	0.13	1.38	.18
	Fixed	Constraint (high vs. low)	-0.06	0.03	-2.01	.04
	Fixed	Stimulus Type (cog vs. control)	0.02	0.03	0.75	.45
	Fixed	GroupBWA:Constraint	0	0.04	-0.12	.89
	Fixed	GroupBWA:Stimulus Type	-0.04	0.04	-1.01	.30
	Fixed	Constraint:Stimulus Type	-0.07	0.06	-1.16	.24
	Fixed	GroupBWA:Constraintc:Stimulus	0.09	0.09	1.04	.29
	Random	Participant (SD)	0.07			
GPD Cog (IA 5)	Fixed	Intercept	5.91	0.11	51.05	< .001
	Fixed	Group (BWA vs. BNC)	0.17	0.17	1	.32
	Fixed	Constraint (high vs. low)	-0.1	0.05	-2.01	.04
	Fixed	Stimulus Type (cog vs. control)	0.01	0.05	0.24	.80
	Fixed	GroupBWA:Constraint	0.04	0.07	0.6	.54
	Fixed	GroupBWA:Stimulus Type	-0.05	0.07	-0.75	.44
	Fixed	Constraint:Stimulus Type	0.05	0.1	0.49	.62
	Fixed	GroupBWA:Constraintc:Stimulus	-0.08	0.15	-0.52	.60
	Random	Participant (SD)	0.12			
	Fixed	Intercept	2.99	0.45	6.62	< .001

RRD Cog (IA 5)	Fixed	Group (BWA vs. BNC)	0.82	0.67	1.21	.24
	Fixed	Constraint (high vs. low)	-0.22	0.2	-1.07	.28
	Fixed	Stimulus Type (cog vs. control)	-0.21	0.2	-1.06	.28
	Fixed	GroupBWA:Constraint	-0.23	0.3	-0.76	.44
	Fixed	GroupBWA:Stimulus Type	-0.09	0.3	-0.3	.75
	Fixed	Constraint:Stimulus Type	-1.08	0.41	-2.62	< .01
	Fixed	GroupBWA:Constraint:Stimulus	0.93	0.61	1.53	.12
	Random	Participant (SD)				
FFD Cog (IA 6)	Fixed	Intercept	5.53	0.03	144.77	< .001
	Fixed	Group (BWA vs. BNC)	0.04	0.05	0.74	.46
	Fixed	Constraint (high vs. low)	0.02	0.02	0.88	.37
	Fixed	Stimulus Type (cog vs. control)	0.02	0.02	0.92	.35
	Fixed	GroupBWA:Constraint	0	0.03	-0.17	.86
	Fixed	GroupBWA:Stimulus Type	0	0.03	0.24	.80
	Fixed	Constraint:Stimulus Type	-0.02	0.04	-0.5	.61
	Fixed	GroupBWA:Constraint:Stimulus	0.08	0.06	1.19	.23
	Random	Participant (SD)	0.01			
GD Cog (IA 6)	Fixed	Intercept	6.21	0.12	51.43	0
	Fixed	Group (BWA vs. BNC)	0.3	0.18	1.67	.11
	Fixed	Constraint (high vs. low)	0	0.04	0.08	.93
	Fixed	Stimulus Type (cog vs. control)	-0.04	0.04	-1.15	.24
	Fixed	GroupBWA:Constraint	0.06	0.06	1	.31
	Fixed	GroupBWA:Stimulus Type	0.01	0.06	0.27	.78
	Fixed	Constraint:Stimulus Type	0.02	0.08	0.28	.77
	Fixed	GroupBWA:Constraint:Stimulus	0.05	0.12	0.45	.64
	Random	Participant (SD)	0.14			
GPD Cog (IA 6)	Fixed	Intercept	7.52	0.13	57.26	< .001
	Fixed	Group (BWA vs. BNC)	0.52	0.19	2.65	.01
	Fixed	Constraint (high vs. low)	-0.08	0.04	-2	.04
	Fixed	Stimulus Type (cog vs. control)	-0.11	0.04	-2.5	.01
	Fixed	GroupBWA:Constraint	-0.05	0.06	-0.81	.41
	Fixed	GroupBWA:Stimulus Type	0.13	0.06	1.96	.05

	Fixed	Constraint:Stimulus Type	-0.18	0.08	-2.1	.03
	Fixed	GroupBWA:Constraint:Stimulus	0.13	0.13	1.03	.29
	Random	Participant (SD)	0.16			
	Fixed	Intercept	3.02	0.46	6.53	< .001
	Fixed	Group (BWA vs. BNC)	0.72	0.69	1.04	.31
	Fixed	Constraint (high vs. low)	-0.48	0.21	-2.25	.02
RRD	Fixed	Stimulus Type (cog vs. control)	-0.34	0.21	-1.62	.10
Cog	Fixed	GroupBWA:Constraint	-0.25	0.31	-0.78	.43
(IA 6)	Fixed	GroupBWA:Stimulus Type	0.49	0.31	1.55	.11
	Fixed	Constraint:Stimulus Type	0.1	0.42	0.24	.81
	Fixed	GroupBWA:Constraint:Stimulus	-0.36	0.63	-0.57	.56
	Random	Participant (SD)	2.02			

Note. *FFD* = First fixation duration; *GD* = Gaze duration; *GPD* = Go-past duration; *RRD* = Rereading duration; *Cog* = Cognate; *IA* = Interest area; *SE* = Standard Error; *t* = t-statistic; *SD* = Standard Deviation

8.2.3.2. Homograph Interference Effects

At interest area 5, there was no reliable evidence that homographs altered early-stage processing in either group (see Table 8.11). The only significant effect across the early-stage measures was a modest main effect of constraint in gaze duration that revealed longer gaze durations under higher semantic constraint ($b = 0.07$, $SE = 0.03$, $t = 2.24$, $p = .03$).

Later measures at interest area 5 showed limited sensitivity to homograph status. Go-past duration did not exhibit significant main effects or interactions involving stimulus type or constraint. Rereading duration, however, showed a significant main effect of stimulus type ($b = -0.54$, $SE = 0.22$, $t = -2.45$, $p = .01$), indicating reduced rereading for homographs relative to homograph controls. This effect was qualified by a stimulus-by-group interaction ($b = 0.90$, $SE = 0.33$, $t = 2.70$, $p < .01$), reflecting a larger homograph-control difference in BWA relative to BNC.

At interest area 6, neither early nor late measures showed reliable effects of homograph status. First fixation duration and gaze duration revealed no main effects or interactions involving stimulus type, constraint, or group (all $ps > .18$). Later measures similarly showed little evidence for homograph-specific processing effects. Go-past duration was longer overall in BWA than BNC ($b = 0.52$, $SE = 0.20$, $t = 2.60$, $p = .02$) but did not differ as a function of homograph status, and rereading duration showed no reliable main effects or interactions.

Taken together, the homograph models provide little evidence that homographs impose consistent interest area-level processing costs during sentence reading in either

group. Homograph status did not reliably affect early-stage measures, nor did it interact with semantic constraint in later processing. The only homograph-related effect—an unexpected reduction in rereading at interest area 5, particularly in BWA—could reflect diminished late-stage reanalysis rather than beneficial lexical processing. Unlike cognates, homograph effects were weak, localized, and did not persist into the sentence-final region, suggesting that lexical ambiguity played a limited role in shaping online reading at specific areas in the sentences.

Table 8.11. Aim 2.2: Bilingual Group x Constraint & Reading Measures Models

Data	Effect	Term	Estimate	SE	t	p-value
FFD (IA 5)	Fixed	Intercept	5.47	0.05	106.4	< .001
	Fixed	Group (BWA vs. BNC)	0.11	0.07	1.52	0.14
	Fixed	Constraint (low vs. high)	0	0.01	0.2	0.83
	Fixed	Group x Constraint	0	0.02	0.4	0.68
	Random	Participant (SD)	0.02			
GD (IA 5)	Fixed	Intercept	5.62	0.08	66.09	< .001
	Fixed	Group (BWA vs. BNC)	0.16	0.12	1.26	0.22
	Fixed	Constraint (low vs. high)	0	0.02	-0.1	0.91
	Fixed	Group x Constraint	0.04	0.03	1.37	0.17
	Random	Participant (SD)	0.06			
GPD (IA 5)	Fixed	Intercept	5.86	0.11	53.11	< .001
	Fixed	Group (BWA vs. BNC)	0.20	0.16	1.21	0.24
	Fixed	Constraint (low vs. high)	0.06	0.03	1.66	0.09
	Fixed	Group x Constraint	-0.03	0.05	-0.55	0.57
	Random	Participant (SD)	0.11			
RRD (IA 5)	Fixed	Intercept	2.77	0.44	6.24	< .001
	Fixed	Group (BWA vs. BNC)	0.85	0.66	1.28	0.21
	Fixed	Constraint (low vs. high)	0.11	0.15	0.79	0.42
	Fixed	Group x Constraint	0.16	0.22	0.75	0.45
	Random	Participant (SD)	1.85			
FFD (IA 6)	Fixed	Intercept	5.54	0.04	133.64	< .001
	Fixed	Group (BWA vs. BNC)	0.05	0.06	0.84	0.4
	Fixed	Constraint (low vs. high)	-0.01	0.01	-0.85	0.39
	Fixed	Group x Constraint	0	0.02	-0.02	0.97
	Random	Participant (SD)	0.01			
GD (IA 6)	Fixed	Intercept	6.25	0.11	52.45	< .001
	Fixed	Group (BWA vs. BNC)	0.30	0.17	1.72	0.1

	Fixed	Constraint (low vs. high)	-0.01	0.03	-0.45	0.65
	Fixed	Group x Constraint	-0.03	0.04	-0.72	0.46
	Random	Participant (SD)	0.13			
GPD (IA 6)	Fixed	Intercept	7.51	0.13	56.66	< .001
	Fixed	Group (BWA vs. BNC)	0.48	0.19	2.41	0.02
	Fixed	Constraint (low vs. high)	0.04	0.03	1.39	0.16
	Fixed	Group x Constraint	0.07	0.04	1.64	0.09
	Random	Participant (SD)	0.17			
RRD (IA 6)	Fixed	Intercept	2.81	0.44	6.24	< .001
	Fixed	Group (BWA vs. BNC)	0.68	0.67	1.01	0.32
	Fixed	Constraint (low vs. high)	0.40	0.15	2.64	< .01
	Fixed	Group x Constraint	0.17	0.22	0.77	0.43
	Random	Participant (SD)	1.90			

Note. *FFD* = First fixation duration; *GD* = Gaze duration; *GPD* = Go-past duration; *RRD* = Rereading duration; *IA* = Interest area; *SE* = Standard Error; *t* = t-statistic; *SD* = Standard Deviation

Given the limited and inconsistent evidence for homograph-related interference in interest area-level eye-movement measures, a secondary analysis examined whether homograph interference might emerge at even later stages of processing indexed by total sentence reading time and accuracy on the comprehension probes. Although these outcomes were analyzed in Aim 2.1, adding in the potential effect of homographs here presented a new analytical question: are sentences that contain homographs associated with globally slowed processing or reduced comprehension that may be observed in sentence reading times and/or comprehension probe accuracy?

For sentence reading time, there was a main effect of group, such that BWA read sentences more slowly overall than BNC ($b = 0.48$, $SE = 0.17$, $t = 2.92$, $p = .01$). There was also a modest main effect of stimulus type, indicating longer sentence reading times for homograph-containing sentences relative to homograph control sentences ($b = 0.03$, $SE = 0.01$, $t = 2.08$, $p = .04$). Although homograph-containing sentences were read more slowly overall, this effect was small and did not vary by group or semantic constraint.

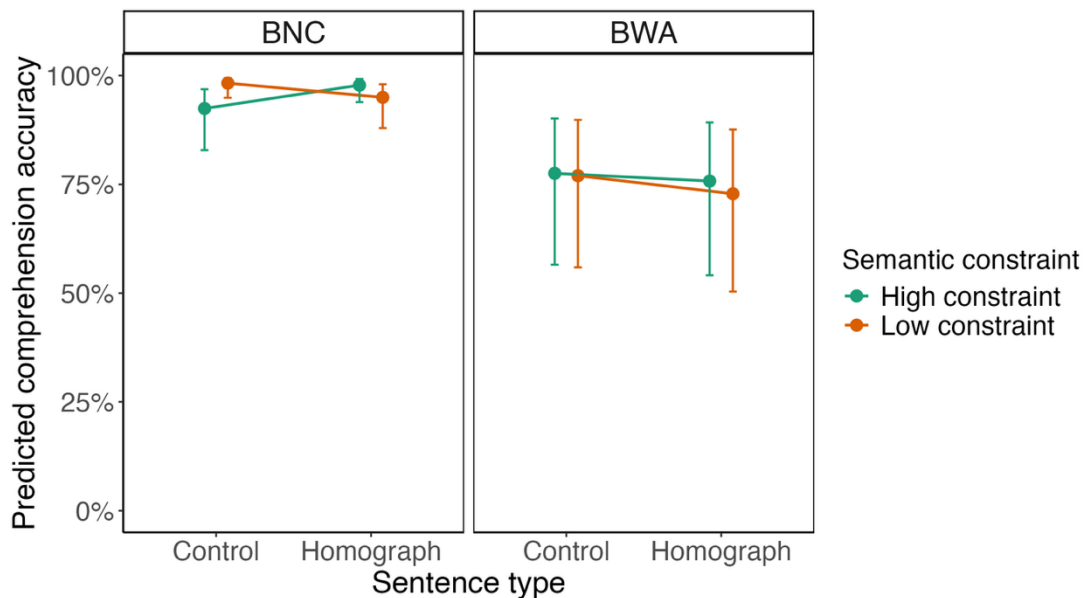
Comprehension probe accuracy was significantly lower in BWA than in BNC overall ($b = -2.18$, $SE = 0.62$, $z = -3.54$, $p < .001$) as was evident in section 8.2.1. Furthermore, there were no main effects of stimulus type or semantic constraint on comprehension accuracy. However, a robust interaction between stimulus type and constraint emerged ($b = -0.60$, $SE = 0.16$, $z = -3.63$, $p < .001$), indicating that the impact of homographs on comprehension was strongly dependent on context. Specifically, homographs were associated with reduced comprehension accuracy in low-constraint sentences, whereas this interference was attenuated in high-constraint contexts, consistent

with the idea that strong semantic support limits lexical competition at the sentence level.

Critically, this pattern was further qualified by a significant three-way interaction with group ($b = 0.57$, $SE = 0.18$, $z = 3.11$, $p = .002$), indicating that the degree to which semantic constraint mitigated homograph interference differed between BWA and BNC. While both groups showed evidence that high constraint reduced the disruptive impact of homographs, this protective effect of context was weaker in BWA. As a result, homograph interference in low-constraint sentences was more pronounced for BWA (see Figure 8.8), reflecting reduced efficiency in using contextual information to resolve lexical ambiguity during sentence comprehension.

The fact that homographs affected comprehension accuracy but did not consistently modulate incremental processing measures is not as contradictory as it may first seem because the two outcomes index different points in the time course of processing. The eye-tracking analyses in Aim 2.3 targeted localized effects at the homograph region and immediate spillover, and they are sensitive to changes in fixation behavior that occurred while the reader was still engaged with the target word or its immediate downstream integration. By contrast, the comprehension probe is an end-state measure that reflects whether the reader ultimately resolved the sentence-level meaning correctly. Homograph interference can therefore emerge robustly at the comprehension level even if it is not associated with a consistent, measurable slowdown in fixation-based indices, especially when the interference reflects failures of ambiguity resolution and integration rather than lexical access.

Figure 8.8 Homograph Effect on Comprehension Probe Accuracy



Caption. A modest effect of homographs vs. control words is shown on comprehension probe accuracy for BWA and BNC. Error bars indicate 95% confidence intervals.

8.3. Discussion

Aim 2 used eye tracking during sentence reading to test whether post-stroke reading differences reflect disruptions in lexical access and/or lexical integration. Eye tracking offers a direct window into online reading because fixations and regressions index moment-to-moment processing demands during comprehension (Rayner, 1998). This distinction is especially relevant in aphasia, where offline sentence-level performance can indicate impairment without clarifying whether difficulty arises during initial lexical access or later integration (Thompson & Choy, 2009; Dickey et al., 2007). Prior eye tracking work in aphasia consistently shows slowed reading and altered gaze behavior relative to controls, often characterized by exaggerated effects, delayed emergence of effects, and/or persisting effects reflected in rereading measures (Knilans & DeDe, 2015; DeDe, 2017; DeDe & Kelleher, 2021; Huck et al., 2017a; Smith et al., 2018). Therefore, the hypotheses for Aim

2 focused on whether group differences between individuals with aphasia and controls would emerge across the time course of processing for sentences differing in semantic constraint, and whether these patterns would vary for bilinguals and monolinguals once both sentence-level and word-level cues were taken into account. The discussion that follows first addresses global sentence-level outcomes before turning to region- and measure-specific effects of semantic constraint and bilingual lexical access.

8.3.1. Global Comprehension Accuracy and Total Sentence Reading Time

The results from Aim 2.1 were focused on whether comprehension accuracy and total sentence reading time distinguished groups based on overall reading behavior. Both the BNC and MNC groups showed substantially higher comprehension accuracy than the BWA and MWA; furthermore, there were no differences in accuracy between the groups with aphasia. A parallel pattern emerged for total sentence reading time: the BNC and MNC read significantly faster than BWA, while MWA did not differ reliably from BWA. These results align with prior eye-tracking studies showing that PWA, in general, tend to read more slowly and are less accurate on comprehension questions than healthy controls (DeDe, 2017; DeDe & Kelleher, 2021; Huck et al., 2017a). They are also consistent with broader descriptions of aphasia-related slowing in sentence comprehension that can reflect delayed lexical access and/or impaired lexical integration (Ferrill et al., 2012; Love et al., 2008; Thompson & Choy, 2009).

A key null result in Aim 2.1 was that the semantic constraint manipulation did not influence comprehension accuracy or total sentence reading time, and there were no reliable group-by-constraint interactions. This finding suggests that semantic constraint

effects in the eye tracking experiment—if they existed at all—were more likely to appear in localized interest-area measures that reflect specific stages of processing, rather than as uniform modulators of reading behavior across whole sentences. This pattern is also compatible with prior eye tracking work in aphasia in which the presence and location of predictability or constraint effects depended strongly on what measures were included and whether the design examined later rereading processes (Knillans & DeDe, 2015; DeDe, 2017; Kim & Bolger, 2020).

8.3.2. Semantic Constraint Effects and the Time Course of Processing in Aphasia

8.3.2.1. *Monolingual Patterns*

Aim 2.2 evaluated whether semantic constraint modulates online reading and whether aphasia alters the timing and persistence of that modulation. The monolingual results provided the clearest evidence that semantic constraint impacts online reading while also illustrating slowed processing associated with aphasia. Across both the target interest area and a spillover region occurring immediately after, MWA showed longer early-stage reading measures and longer go-past durations relative to MNC, indicating that aphasia-related slowing was not confined to later integration but was evident from the earliest stages of processing onward. Broadly, this pattern aligns with eye tracking evidence that PWA produce longer reading durations, make more regressions, and skip words less often than healthy controls, reflecting increased processing demands during sentence reading (DeDe, 2017; Smith et al., 2018; Knollman-Porter et al., 2023; Hux et al., 2024).

Semantic constraint effects in the monolingual groups were also present. At the target region (interest area 5), low constraint elicited longer first fixation and gaze

durations, consistent with the view that low predictability can influence early processing when lexical access is supported by contextual pre-activation (Rayner, 1998; Kim & Bolger, 2020). However, constraint effects were also present in later measures, including robust increases in rereading duration under low constraint. At the spillover, prepositional phrase region (interest area 6), constraint effects were reduced for early measures and were most apparent in late-stage measures. This pattern is broadly compatible with accounts in which sentence context exerts influence both during initial lexical processing and during integration, with especially reliable effects appearing when readers must commit to, revise, or repair a sentence interpretation (Thompson & Choy, 2009; Knilans & DeDe, 2015; DeDe & Kelleher, 2021). It also matches the general logic emphasized in the Chapter 4 review that delayed or persistent effects can be most visible when rereading-sensitive measures are included (Knilans & DeDe, 2015; DeDe, 2017), and helps explain why studies that did not include rereading time sometimes reported less evidence for delayed/persisting patterns (Kim & Bolger, 2020; DeDe, 2020). Crucially, group-by-constraint interactions were not significant in any of the mixed-effects models, indicating that the magnitude of semantic constraint effects did not differ between MNC and MWA. This pattern suggests that aphasia primarily affects the efficiency and timing of sentence processing rather than an ability to use sentence context to support comprehension. Although MWA exhibited longer reading times and more persistent rereading overall, these delays were not selectively amplified under low-constraint conditions. Instead, aphasia-related slowing and constraint-related effects operated largely independently: low constraint increased processing demands for both groups, while aphasia introduced a

generalized slowdown that was evident regardless of contextual predictability.

8.3.2.2. Bilingual Patterns

The bilingual Aim 2.2 results were more limited and therefore minimally supported the hypotheses outlined in Chapter 6. Unlike the monolingual comparisons, there was little evidence of broad BWA–BNC differences across early measures in interest area 5. Instead, the main bilingual group difference was localized to the spillover region: BWA showed longer go-past durations than BNC at interest area 6 and both bilingual groups showed more rereading for low constraint sentences than high. Importantly, the MWA and MNC showed these same patterns of effects as well which suggests concordance between processing behaviors as a result of aphasia (on the part of the BWA and MWA). This selective late-stage slowing at a spillover region is consistent with prior findings that PWA can show delayed or downstream effects even when earlier measures appear less differentiated (Hsu et al., 2014; Huck et al., 2017b; DeDe & Kelleher, 2021). Interpreted through DeDe’s two-tier framework, the bilingual pattern is consistent with a narrower version of the two-stage account: the clearest aphasia-linked divergence appears in later measures that reflect integration difficulty and regressive processing, rather than in early-stage processing measures that reflect first-pass reading (Knilans & DeDe, 2015; DeDe, 2017). At the same time, because this result was localized, the most defensible conclusion is that this design was most sensitive to bilingual group differences at later stages, not that early bilingual processing is unaffected by aphasia. Once more, the group-by-constraint interactions were not significant nor were the main effects of constraint which suggests that any sensitivity to semantic constraint was processed similarly across the two groups.

Even more crucially, these effects were absent in the bilingual groups whereas they were readily apparent in the monolinguals. One possible explanation for this apparent null finding is that in bilingual readers, semantic constraint interacts with lexical properties such as cognate status to shape online reading behavior. If contextual support primarily enhances facilitation for lexically privileged items, rather than exerting a uniform effect across all words, analyses that collapse across lexical types may obscure constraint effects at the group level. Consistent with this account, Aim 2.3 revealed that cognate facilitation was modulated by semantic constraint, with stronger benefits emerging in high-constraint contexts. This pattern suggests that semantic constraint in bilingual reading may be expressed through interactions with lexical overlap, providing a plausible explanation for the absence of a standalone constraint effect in Aim 2.2. Another potential explanation, of course, is the reduced sample size for the bilingual groups relative to the monolingual groups produced fewer opportunities to detect processing differences involving semantic constraint and group when compared to the monolingual analyses.

8.3.3. Bilingual Lexical Effects and Semantic Constraint

Aim 2.3 examined whether bilingual groups show cognate facilitation and homograph interference during sentence reading, and whether semantic constraint modulates those lexical effects. The results were mixed and, in several respects, did not match the strongest predictions derived from prior bilingual sentence-reading work.

8.3.3.1. *Cognate Facilitation*

For cognates, the canonical prediction from bilingual interactive activation accounts is that lexical overlap across languages can facilitate processing (Carramazza &

Brones, 1979; Dijkstra et al., 2019), and that the expression of this effect in sentences may vary depending on contextual constraint (Libben & Titone, 2009; Schwartz & Kroll, 2006). In the present data, cognate status did not reliably affect early-stage measures (first fixation duration and gaze duration) at either interest area, and there was no clear evidence that BNC showed a robust early cognate advantage. Instead, cognate-related structure emerged selectively in later measures and was contingent on semantic constraint, with this pattern expressed in BWA and BNC. At interest area 5, a constraint-by-stimulus interaction in rereading duration indicated reduced rereading for cognates in high-constraint contexts. At interest area 6, go-past duration revealed both cognate facilitation and a constraint-by-stimulus interaction in which facilitation effects were stronger in high-constraint sentences and reduced in low-constraint contexts. These findings can be interpreted in light of the original cognate hypotheses for Aim 2.3. We predicted that BNC would show early cognate facilitation that would be modulated by semantic constraint, with high-constraint contexts attenuating lexical effects at later stages of processing, and that BWA would show exaggerated, delayed, and more persistent cognate facilitation. The present data do not support the prediction of robust early cognate facilitation in the BNC, nor the expectation that semantic constraint would immediately amplify cognate effects at the target region. Instead, cognate facilitation emerged selectively in later measures and was contingent on semantic constraint with facilitation strongest in high-constraint contexts and reduced under low constraint.

Importantly, this interaction was most evident at the spillover region and was more pronounced in BWA, consistent with the hypothesis that bilingual readers with aphasia rely

more heavily on delayed, integration-based mechanisms to recruit lexical overlap during sentence comprehension. Thus, while the predicted early amplification of cognate facilitation by semantic constraint was not observed, the results support the broader hypothesis that interactions between lexical overlap and semantic context are delayed and persistent in bilingual aphasia. These findings refine the original predictions by suggesting that semantic constraint does not enhance cognate processing during initial lexical access but instead shapes how lexical overlap is leveraged during later stages of sentence integration, particularly in BWA.

However, this pattern of results was not found by Libben and Titone (2009) where young healthy bilinguals demonstrated lexical effects that were evident early and persisted into later measures primarily when sentence constraint was low. However, prior bilingual sentence work has also reported that the interaction between lexical effects and context is mixed across studies (Libben & Titone, 2009; Schwartz & Kroll, 2006; van Assche et al., 2011), and, as mentioned in Chapters 5 and 6, the BIA+ model itself predicts that sentence context can attenuate lexical effects by constraining selection (Dijkstra & van Heuven, 2002; Schwartz & Kroll, 2006). One interpretation that remains consistent with that framework is that, in this experiment, cognate status influenced processing primarily during later integration/reanalysis stages rather than during initial access at the target, and that high constraint provided a stronger scaffold for committing to a context-consistent interpretation in which shared cross-language representations could be exploited. Stated differently, rather than serving as a compensatory cue when context is weak, cognates may have facilitated efficient resolution when context strongly supported the overlapping

semantic and orthographic features (Libben & Titone, 2009; Dijkstra & van Heuven, 2002), thereby reducing the need for rereading. As a consequence, cognate facilitation in sentence reading was detectable in this dataset primarily as a late, context-dependent effect, localized to specific regions and measures rather than expressed uniformly across early stages of processing.

8.3.3.2. Homograph Interference

For homographs, BIA+ predicts interference when orthography overlaps but meanings diverge, reflecting increased competition that must be resolved for successful integration (Beauvillain & Grainger, 1987; de Groot et al., 2000; Dijkstra et al., 1999; Dijkstra et al., 2000). In sentence reading, prior eye-tracking work suggests homographs can produce early costs and, depending on constraint, later costs that persist when context is low (Libben & Titone, 2009), though not all paradigms detect homograph effects reliably (Schwartz & Kroll, 2006). In the interest-area models here, homograph status did not yield consistent evidence of interference: there were no reliable homograph effects in early measures, no consistent modulation by semantic constraint, and limited evidence at interest area 6. The clearest interest-area homograph result was an unexpected reduction in homograph rereading at interest area 5, particularly in BWA. This finding should naturally be treated with caution. One possibility may be that homographs triggered different processing strategies that resulted in reduced lexical access and therefore less rereading overall (i.e., the homographs were difficult targets for word retrieval). Under this account, homograph-related disruption would be expected to emerge not as localized slowing, but at more global levels of processing, such as increased sentence reading times or reduced

comprehension accuracy, a pattern that is borne out in the sentence-level results described below. Taken together, these findings suggest that homograph-related difficulty in bilingual sentence reading may manifest primarily during later integration and interpretation rather than as consistent early interference at the word level.

Critically, a secondary analysis at the sentence level did reveal theoretically coherent homograph effects. In overall sentence reading time, sentences containing homographs were read more slowly than homograph control sentences. Moreover, there was a homograph-by-constraint pattern in comprehension: the BWA showed reduced comprehension question accuracy for sentences containing homographs, especially low constraint sentences, when compared to BNC. These outcome-level patterns align with the core BIA+ prediction that context can constrain selection and reduce lexical competition (Dijkstra & van Heuven, 2002; Libben & Titone, 2009). In this case, low semantic constraint magnified the processing costs associated with the homographs and this interaction manifested in downstream comprehension accuracy differences. These patterns are also consistent with aphasia accounts emphasizing disrupted or less efficient lexical integration, particularly when ambiguity must be resolved using contextual support (Thompson & Choy, 2009; DeDe & Kelleher, 2021). The fact that this effect emerged more clearly in at the sentence-level than in interest-area timing measures suggests that, in this experiment, homograph difficulty may have manifested as distributed or downstream consequences for sentence interpretation rather than as a localized increase in processing time at the homograph region itself.

As suggested by the pattern of results in Aim 2.3, the dissociation between comprehension accuracy effects and the absence of consistent homograph effects in incremental eye-movement measures is not inherently contradictory. The eye-tracking analyses in Aim 2.3 were designed to capture localized effects during initial encounters with the homograph and its immediate spillover, whereas comprehension probes index the ultimate success of sentence-level interpretation. As a result, homograph interference may manifest reliably at the level of comprehension even when it does not produce a stable slowdown in early fixation-based measures. This pattern is consistent with the view that homograph-related difficulty arises primarily during ambiguity resolution and integration, rather than during initial lexical access.

8.3.3.3. Weak Control Effects

A central interpretive challenge for Aim 2.3 is that the BNC did not consistently show the robust cognate facilitation and homograph interference patterns often reported in bilingual eye-tracking sentence studies (Libben & Titone, 2009) or in sentence-level paradigms manipulating constraint (Schwartz & Kroll, 2006). One plausible explanation is related to task difficulty and the structure of the stimuli. The sentences were designed to be short and syntactically simple for use with individuals with aphasia, which may have reduced processing demands for the control participants and minimized the need for lexical-level cross-language cues to support comprehension. BIA+ explicitly predicts that sentence context constrains lexical selection (Dijkstra & van Heuven, 2002), and when the overall sentence-level processing problem is easy, non-selective activation may still occur but yield small behavioral consequences that are difficult to detect in interest area timing

measures. This interpretation is compatible with the mixed evidence for whether lexical effects are eliminated in high constraint contexts (Libben & Titone, 2009; Schwartz & Kroll, 2006; van Assche et al., 2011) and with the broader notion that top-down context can reduce the need for lexical cues during sentence reading (Altarriba et al., 1996; Duyck et al., 2007). Another possibility is that evaluating the three-way interaction between group x semantic constraint x cognate/homograph was underpowered based on the present number of bilingual individuals.

8.3.4 Evidence for Different Processing Strategies by Language Status

Across Aim 2, the monolingual results align well with the broader aphasia eye-tracking literature showing widespread slowing and increased late-stage processing demands (DeDe, 2017; Smith et al., 2018; Knilans & DeDe, 2015). The bilingual results diverge and provide more limited support for these ideas: BWA–BNC differences were concentrated in late-stage go-past duration and rereading duration at a spillover region across all sentences, a pattern that is compatible with delayed or downstream integration costs (Hsu et al., 2014; DeDe & Kelleher, 2021) but does not show the broad early-and-late exaggeration seen in some prior studies (DeDe, 2017; Johnson & Rayner, 2007). Taken together, Aim 2 supports the general claim that aphasia impacts online reading in ways that are often most evident during later integration and reanalysis, a pattern that emerges both in the modulation of lexical effects and in sentence-level measures of comprehension and processing (Kim & Bolger, 2020; Huck et al., 2017a).

8.3.5. Limitations and Future Directions

The primary limitation for Aim 2, particularly Aim 2.3, is power to detect subtle lexical effects and higher-order interactions. This limitation is especially consequential in bilingual sentence reading, where effects can depend on the interaction between lexical status and sentence context and may appear in specific measures and regions over time (Libben & Titone, 2009; van Assche et al., 2011). A second limitation is that the stimulus characteristics could have reduced processing demands. Short, simple active sentences may have constrained the need for reanalysis, thereby attenuating the magnitude and time course of cognate facilitation and homograph interference especially in healthy bilinguals, even if non-selective access was present (Dijkstra & van Heuven, 2002). Relatedly, semantic constraint did not affect global comprehension or total sentence reading time (Aim 2.1), suggesting that the constraint manipulation may not have been strong enough to shift end-state performance in this task context, even though localized effects were detectable in specific measures at the interest area-level.

Future work can build directly on these results by increasing the processing demands that are most likely to elicit measurable integration difficulty and lexical competition during reading. Designs with longer sentences and greater syntactic complexity have been informative in aphasia eye-tracking studies for revealing delayed and persistent effects (Knillans & DeDe, 2015; DeDe, 2017; DeDe & Kelleher, 2021). For bilingual lexical effects, increasing ambiguity pressure for homographs (e.g., embedding them in passive sentences over actives) could increase sensitivity to context-dependent interference effects reported in prior bilingual sentence-reading studies (Libben & Titone,

2009). Finally, because the clearest homograph signal emerged in comprehension accuracy rather than in interest-area timing measures, future paradigms could more tightly align comprehension probes with ambiguity resolution demands to better connect on-line disruption with downstream comprehension outcomes (Schwartz & Kroll, 2006; Libben & Titone, 2009).

Future work could also examine whether online reading patterns differ as a function of trial-level comprehension success, particularly once larger bilingual samples are available. Although many eye-tracking studies report comparable reading behavior when analyses are restricted to correctly answered trials versus all trials, this assumption has rarely been evaluated in bilingual aphasia. Given that homograph effects in the present study were most robust at the level of comprehension accuracy rather than incremental timing measures, separating trials based on comprehension outcome may help clarify whether late integration difficulty manifests differently on trials that ultimately result in misinterpretation. Such analyses would provide a more direct link between online disruption and downstream comprehension failure and would help determine whether the absence of strong lexical effects in early measures reflects true processing similarity across trials or averaging across qualitatively distinct reading outcomes.

Overall, Aim 2 strengthens two conclusions. First, sentence reading is reliably compromised in aphasia with the clearest and most consistent effects emerging in measures that index later integration and reanalysis (Thompson & Choy, 2009; Knilans & DeDe, 2015; DeDe & Kelleher, 2021). Second, bilingual lexical effects in sentence reading were detectable but weaker and occurred later than predicted, potentially highlighting the

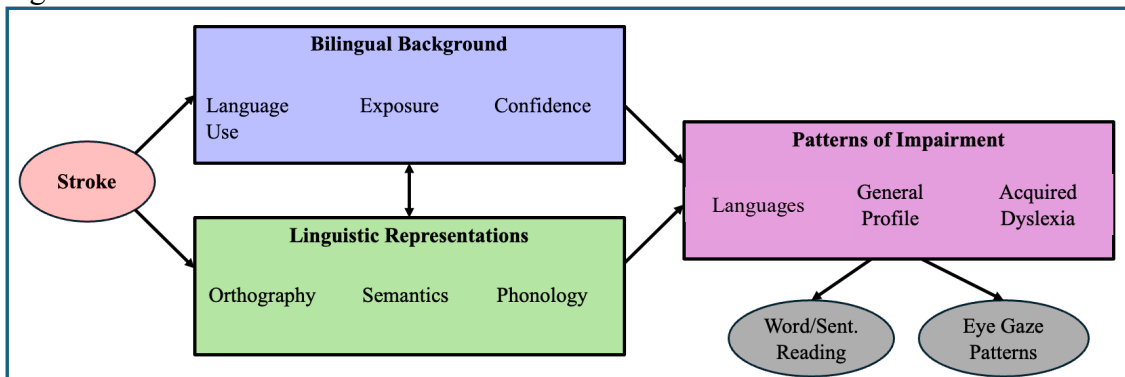
importance of task demands and sentence structure for observing cognate facilitation and homograph interference during online comprehension (Dijkstra & van Heuven, 2002; Libben & Titone, 2009; Schwartz & Kroll, 2006).

9. OVERALL SUMMARY & DISCUSSION

9.1. Overall Summary

The overarching goal of this dissertation was to characterize reading impairment in Spanish–English BWA by integrating clinical assessment with online measures of reading. As outlined in Figure 1.1, the motivating framework assumes that stroke induces a system-level disruption that simultaneously affects linguistic representations and bilingual experience, and that these changes interact over time to give rise to observable patterns of impairment. The two empirical aims of the dissertation were designed to capture complementary consequences of this disruption. Aim 1 examined reading outcomes using clinical and behavioral measures to investigate profiles of impairment severity, acquired dyslexia characteristics, and potential cross-language effects on reading abilities. Aim 2 examined the moment-to-moment dynamics of sentence reading using eye tracking, providing insight into how damaged representations affect online processing. Considered together, the results from these aims converge on a coherent account of reading impairment in bilingual aphasia while also revealing important dissociations between offline performance and online processing.

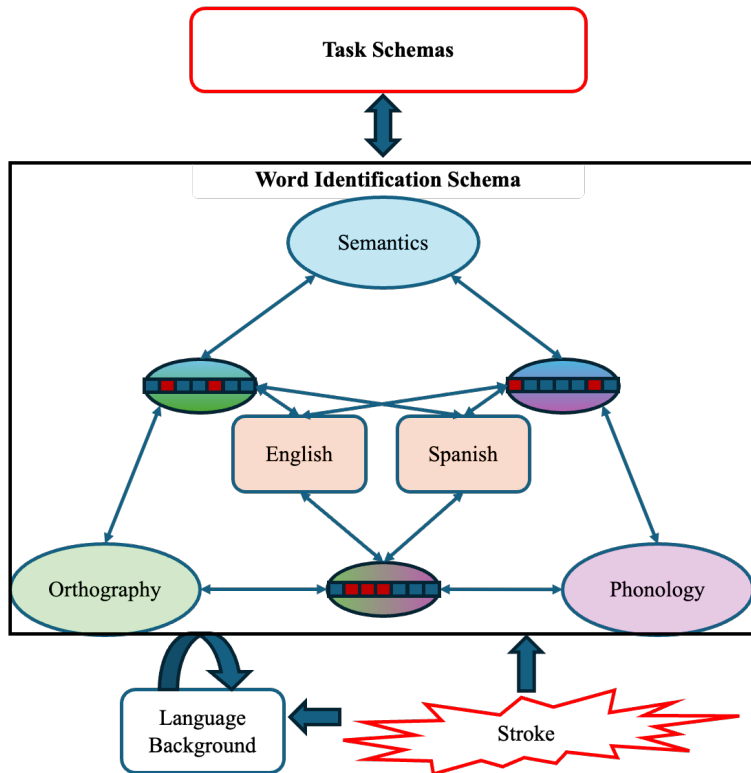
Figure 1.1 Framework for Dissertation Work



The integration of findings across aims is most clearly understood within the Bilingual Interactive Activation for Aphasia model illustrated in Figure 6.1. The BIAA model builds on the BIA+ and Triangle frameworks by assuming fully interactive, language-nonspecific processing across orthographic, phonological, and semantic representations, while explicitly incorporating the effects of stroke and changes in bilingual experience. Within this architecture, damage alters resting activation levels and the efficiency with which information propagates across representational levels. This perspective provides a principled explanation for why reading impairment in bilingual aphasia manifests both as stable outcome differences on clinical measures and as altered processing dynamics during online reading.

Viewed through this lens, the integration of Aims 1 and 2 clarifies how reading impairment manifests across assessment contexts in bilingual aphasia. Aim 1 showed that reading performance is systematically related to spoken-language impairment and to underlying semantic and phonological abilities, consistent with primary systems accounts of reading. In addition, reading performance in BWA was sensitive to cross-language phonological and orthographic factors, indicating that shared representational systems constrain reading behavior across languages following stroke. Aim 2 extended these findings by showing that these similar factors influence online reading behavior, particularly in measures sensitive to later stages of integration. Together, the findings indicate that reading impairment in bilingual aphasia reflects disruptions to shared linguistic systems that are evident both in offline outcomes and in the temporal dynamics of online processing.

Figure 6.1. Bilingual Interactive Activation for Aphasia Model



9.2. Aim 1 Summary

Aim 1 demonstrated that reading is broadly impaired in Spanish–English BWA relative to BNC, and that the structure of this impairment closely parallels patterns reported in monolingual aphasia. As in the monolingual literature, the clearest group-level effect was a robust disadvantage for individuals with aphasia in single-word reading accuracy, even after accounting for demographic variables and premorbid reading ability. Oral reading showed a strong and reliable patient–control difference, whereas reading comprehension was less sensitive to group status, consistent with evidence from MWA that reading aloud is disproportionately vulnerable due to its reliance on explicit phonological output processes (Jefferies & Lambon Ralph, 2006; Patterson & Lambon Ralph, 1999). At the individual level, performance varied across participants and

languages, underscoring the limitations of inferring bilingual reading ability from a single task or language (Goral, 2019; Kuzmina et al., 2019).

Subtype analyses further reinforced similarities between bilingual and monolingual aphasia. Phonological dyslexia was the most frequent profile observed in both MWA and BWA, consistent with primary-systems accounts in which compromised phonological representations affect both spoken and written language (Lambon Ralph & Patterson, 2007; Madden et al., 2018; Rapcsak et al., 2008; Woollams, 2014). At the same time, cross-language concordance of subtype classification was relatively uncommon in BWA, indicating that the behavioral expression of reading impairment can diverge across a bilingual individual's two languages following stroke, even when impairment arises from shared underlying deficits. Critically, this pattern reflects the consequences of lesioning a bilingual reading system rather than the presence of qualitatively distinct mechanisms in bilingual aphasia. In contrast to monolingual reading systems, bilingual reading relies on partially overlapping orthographic, phonological, and semantic representations that are continuously shaped by differential language experience and cross-language competition. Stroke-related damage to this shared system therefore disrupts not only the efficiency of component processes, but also the balance of activation and competition between languages. As a result, the same lesion can yield non-parallel subtype expressions across languages; the observed impairment profile then reflects how premorbid language experience modulates the reorganization and competitive dynamics of the damaged system (Goral & Lerman, 2020; Kuzmina et al., 2019).

Consistent with this interpretation, premorbid reading ability independently predicted post-stroke reading accuracy, indicating that the strength and specificity of bilingual representations established prior to injury continue to constrain performance after stroke (Gray & Kiran, 2012). Differences in literacy acquisition, instructional context, and habitual reading across languages may therefore give rise to concordant or discordant dyslexia profiles once central semantic and phonological systems are compromised. From this perspective, cross-language differences in subtype expression do not contradict shared-representation models such as the BIAA; instead, they reflect how damage to modality-independent systems (Dijkstra et al., 1999; Dijkstra & van Heuven, 2002;) is filtered through bilingual learning histories.

Model-based analyses in Aims 1.2 and 1.3 provided converging support for this integrated account. Across oral reading tasks, phonological ability was the strongest and most consistent predictor of accuracy, including nonword decoding, whereas semantic ability contributed selectively to real word reading and was more strongly associated with reading comprehension (Jefferies & Lambon Ralph, 2006; Woollams, 2014). Crucially, these patterns of results were consistent with monolingual-only studies (Madden et al., 2018) which suggest that they are a consequence of aphasia across monolingual and bilingual reading systems. Cross-language similarity effects further indicated preserved non-selective activation following stroke: greater phonological overlap facilitated word reading, whereas greater orthographic overlap was associated with reduced accuracy, consistent with facilitation and competition operating within a shared bilingual lexicon (Dijkstra et al., 1999; van Assche et al., 2011).

Together, the findings from Aim 1 demonstrate that bilingual alexia is grounded in disruptions to shared semantic–phonological systems that mirror those observed in monolingual aphasia, while remaining sensitive to cross-language activation dynamics and individual literacy histories. These results move the field beyond single-language characterizations of acquired dyslexia by showing that valid clinical and theoretical accounts of bilingual reading impairment require direct assessment of both languages and explicit consideration of how bilingual experience shapes the expression of impairment within an integrated reading system (Goral, 2019).

9.3. Aim 2 Summary

Aim 2 examined how aphasia affects the time course of sentence reading and how semantic context and bilingual lexical cues shape online comprehension in bilingual and monolingual readers. At the sentence level, both comprehension accuracy and total reading time reliably distinguished individuals with aphasia from controls across language groups, indicating that stroke impacts global reading efficiency and downstream comprehension during connected reading (DeDe, 2017; Hux et al., 2024; Knollman-Porter et al., 2023; Smith et al., 2018). In contrast, semantic constraint did not modulate these global measures, suggesting that contextual effects were expressed primarily through localized processing dynamics rather than uniform shifts in end-state performance (Kim & Bolger, 2020; Rayner, 1998).

Eye tracking analyses clarified how these global differences arise over time. In monolingual aphasia, reading disruption was broad and evident across early and late measures, consistent with prior work showing pervasive slowing and increased rereading

during sentence processing (DeDe, 2017; DeDe & Kelleher, 2021; Knilans & DeDe, 2015). Sensitivity to semantic constraint was preserved, but its effects were additive with aphasia-related slowing rather than qualitatively altered, aligning with accounts in which aphasia primarily reduces processing efficiency while leaving context use intact (DeDe & Kelleher, 2021; Thompson & Choy, 2009). In bilingual aphasia, group differences were more circumscribed and emerged most clearly during later stages of processing, particularly in measures indexing regression and integration at the spillover region. This pattern should not be interpreted as evidence that bilingualism fundamentally alters the locus of aphasia-related reading disruption. Rather, it likely reflects a combination of reduced power in the bilingual sample and the fact that the present design was most sensitive to later, integration-related costs in bilingual readers. Under relatively simple sentence structures and modest ambiguity demands, early-stage lexical effects may have been attenuated or obscured, whereas later measures captured cumulative processing difficulty more reliably (DeDe, 2017; Knilans & DeDe, 2015). From this perspective, the bilingual results suggest that aphasia-related disruption is present throughout processing but was most detectable during sentence-level integration under the current task constraints.

Analyses of bilingual lexical cues further refined this account. Cognate facilitation and homograph interference were detectable but did not emerge as robust early effects at the word level. Instead, these lexical influences were context dependent and most apparent in later measures and sentence-level outcomes, consistent with evidence that lexical effects in bilingual sentence reading can vary as a function of contextual constraint and processing demands (Libben & Titone, 2009; Schwartz & Kroll, 2006). Cognates primarily facilitated

processing when semantic constraint was strong, consistent with the view that cross-language overlap can support integration and reduce reanalysis when contextual support converges on the intended meaning (Dijkstra & van Heuven, 2002; Libben & Titone, 2009). Homographs, in contrast, exerted their clearest effects on comprehension accuracy and overall sentence reading time, particularly under low constraint, consistent with the idea that ambiguity-related competition may be expressed most reliably as downstream integration difficulty when context is insufficient to constrain selection efficiently (Libben & Titone, 2009; Schwartz & Kroll, 2006).

Together, the findings from Aim 2 indicate that aphasia alters the temporal dynamics of sentence reading without eliminating the use of semantic context or bilingual lexical representations. For bilingual readers with aphasia, cross-language activation and lexical competition remain operative, but under the present task demands they were expressed most reliably as delayed or distributed costs that affect integration and interpretation rather than as early, localized effects (Dijkstra & van Heuven, 2002; Libben & Titone, 2009). These results align with interactive accounts of bilingual reading while underscoring the importance of task demands and measurement sensitivity for detecting when and where lexical and contextual effects emerge during online comprehension (Libben & Titone, 2009; Schwartz & Kroll, 2006).

9.4. Integrating Aims 1 and 2

9.4.1 Aphasia and Bilingualism in the Magnitude of Reading Impairment

An important interpretive issue in this work concerns how aphasia and bilingualism jointly contribute to the magnitude of reading impairment. Although the present analyses did not center on direct contrasts between monolingual and bilingual individuals with aphasia across all aims, several findings from Aim 1 provide evidence for these contrasts. In particular, premorbid reading ability emerged as a significant predictor of post-stroke reading performance in bilingual readers in Aim 1.1. After accounting for this source of variance, the estimated effect of aphasia on reading accuracy was nearly identical in bilingual and monolingual models, suggesting comparable levels of impairment at the group level.

This pattern supports the view that the overall magnitude of reading impairment is primarily driven by aphasia-related disruption to shared semantic and phonological systems, rather than by bilingualism per se. Bilingualism, in turn, appears to shape how that impairment is expressed across languages and tasks, through differences in representational strength, language use, and cross-language interaction established prior to injury. Such an interpretation is consistent with prior work showing that premorbid literacy and language experience continue to constrain performance following stroke, even when central language systems are compromised (Gray & Kiran, 2012; Goral, 2019). From this perspective, bilingual aphasia does not necessarily entail greater or lesser impairment than monolingual aphasia but rather reflects the interaction of aphasia with a bilingual language

system, yielding greater variability in the behavioral expression of impairment across languages.

9.4.2. Aligning Offline and Online Measures of Reading Comprehension

A second interpretive issue concerns how offline reading comprehension deficits relate to online measures of sentence processing and comprehension. In the present study, bilingual readers with aphasia demonstrated reduced accuracy on standardized measures of sentence comprehension as well as lower accuracy on comprehension probes administered during the eye-tracking task. At the same time, eye-movement differences at the target region were relatively subtle, and more consistent group differences emerged in spillover regions and in sentence-level reading time.

Taken together, these findings suggest that small or localized disruptions during online processing may accumulate over the course of a sentence and manifest as downstream comprehension failures. Within eye-tracking paradigms, such effects are commonly interpreted as reflecting delayed integration or reanalysis processes, rather than immediate lexical access difficulty (Rayner, 1998; DeDe, 2017). Under this view, the absence of large early effects in the bilingual group does not imply intact processing but rather indicates that the consequences of disruption may only become detectable once information must be integrated across words and maintained over time.

The offline comprehension results from Aim 1 further clarify this relationship. In bilingual readers with aphasia, both semantic and phonological abilities independently predicted sentence comprehension accuracy. From a primary systems or triangle-model perspective, this pattern reflects the fact that sentence comprehension depends on the

coordinated activation of semantic representations and phonological input, including function words and morphological markers that carry limited semantic content but are critical for establishing syntactic and thematic relations (Jefferies & Lambon Ralph, 2006; Lambon Ralph & Patterson, 2007). Even in relatively simple sentences, degraded phonological input can compromise access to these elements, thereby affecting sentence interpretation. The convergence of offline and online findings therefore supports a view in which comprehension deficits arise not from a single point of failure, but from the cumulative effects of reduced efficiency across interacting components of the language system.

9.4.3. Early and Late Processing Differences and Their Implications for Reading

The distinction between early and late stages of processing provided important insight into the nature of reading difficulty in aphasia. Measures such as total sentence reading time collapse information across regions and capture the cumulative cost of processing a sentence, including integration demands and short-term maintenance of sentence information prior to comprehension judgments. Although such measures do not isolate specific loci of difficulty, they are sensitive to the downstream consequences of subtle disruptions that may not be detectable at individual regions of interest.

Distinguishing early and late effects also informs interpretation of how readers with aphasia use linguistic information during reading. In the present data, monolingual readers with aphasia showed evidence of early sensitivity to semantic constraint, followed by increased rereading under low-constraint conditions, suggesting preserved use of contextual information alongside increased integration demands. In bilingual readers with

aphasia, lexical and contextual effects were more apparent in later measures, indicating that facilitation and interference may emerge primarily during integration rather than initial access. These timing differences suggest that aphasia does not eliminate sensitivity to lexical or contextual cues but alters when and how such information is recruited during comprehension.

From a clinical perspective, these observations highlight the importance of considering processing dynamics, not just end-state accuracy, when characterizing reading impairment. If facilitation from context or cross-language overlap emerges later in processing, then interventions that encourage strategic rereading or support integration may be particularly beneficial. At the same time, the absence of clear differences in comprehension accuracy between individuals who reread more versus less (not examined in these data) could suggest that increased rereading is not uniformly advantageous, underscoring the need for individualized approaches that take processing efficiency and strategy use into account. Future work linking eye-movement patterns to treatment outcomes will be critical for determining how timing differences in processing can be leveraged to support reading rehabilitation.

9.4.4. Timing of cognate facilitation

The timing of cognate facilitation observed in the present study also warrants careful interpretation. In contrast to many studies reporting early cognate facilitation effects in young adult bilinguals (Libben & Titone, 2009), facilitation in the present data emerged most reliably in later-stage measures, including rereading and sentence-level outcomes. One factor that may contribute to this difference is the age of the participants.

Both healthy controls and individuals with aphasia in this study were older adults, and age-related changes in processing speed and lexical access are known to influence the timing of facilitation effects during reading (Rabaglia & Salthouse, 2011; Salthouse, 1996).

From this perspective, delayed cognate facilitation does not imply the absence of facilitation, but rather suggests that cross-language overlap may exert its influence at later stages of processing in older readers. Aphasia may further shift the timing of these effects by reducing overall processing efficiency, thereby delaying the point at which cross-language support becomes beneficial. The observation that similar timing patterns were present in older healthy bilinguals supports the view that aging and bilingualism jointly shape when facilitation emerges, independent of impairment.

The present findings also raise the question of whether cognate facilitation functions as a core access mechanism or as a form of repair during reading in aphasia. If aphasia primarily delays the time course of processing, then facilitation emerging in later measures could still reflect support for lexical retrieval rather than post-hoc repair. However, the interaction between cognate status and semantic constraint, and the prominence of facilitation in later-stage measures, are also compatible with an interpretation in which cognates support integration or reanalysis when processing is challenged. Disentangling these possibilities will require future work directly comparing younger and older bilingual readers, as well as examining how language dominance and language of reading modulate the timing of cognate effects.

9.4.5. Homograph Effects and Downstream Comprehension

Finally, the pattern of effects observed for homographs raises further questions about how lexical ambiguity is processed during reading in aphasia. In the present data, homographs were associated with downstream costs in comprehension accuracy and sentence reading time, despite showing reduced rereading (relative to matched control words) in some eye-movement measures. Importantly, reduced rereading should not be interpreted as evidence of reduced difficulty. Rather, rereading is widely understood as a strategic response to detected processing difficulty, supporting reanalysis and integration when comprehension is challenged (Rayner, 1998; DeDe & Kelleher, 2021).

One plausible interpretation is that readers with aphasia may disengage from particularly challenging lexical items, resulting in fewer rereading attempts but greater downstream consequences for sentence-level interpretation. Such disengagement could reflect reduced efficiency in lexical access or word retrieval processes following stroke, making reanalysis effortful or ineffective. In bilingual readers, this difficulty may be compounded by the need to resolve competition between multiple lexical representations associated with a single orthographic form. Under this account, homographs may be identified as difficult early on, but insufficient resources or reduced processing efficiency may limit successful reanalysis, leading to downstream effects on comprehension accuracy and overall sentence processing time.

This interpretation is consistent with interactive models in which lexical ambiguity effects are not confined to early stages of processing but can persist or re-emerge during later integration when contextual support is insufficient to fully constrain meaning

selection (Dijkstra & van Heuven, 2002; Libben & Titone, 2009). Within aphasia, such delayed or distributed costs may be especially likely, as reduced processing efficiency limits the system's ability to resolve competition quickly and reliably.

9.5. Limitations & Future Directions

Several limitations constrain the extent to which the two aims can be directly linked. Although the results converge conceptually, the dissertation was not designed to formally map individual clinical metrics onto specific eye-movement signatures. In addition, Aim 2 focused on sentence-level comprehension, whereas Aim 1 encompassed a broader range of reading tasks, limiting one-to-one correspondence across measures. These limitations do not undermine the conclusions of either aim but rather reflect the challenges inherent in integrating offline and online assessments of language processing in aphasia.

A further limitation of Aim 2 concerns sample size in the bilingual eye-tracking analyses. The relatively small number of BWA and BNC may have limited power to detect subtle early-stage lexical effects and higher-order interactions, particularly those involving semantic constraint and lexical status. As a result, the absence of robust early cognate or homograph effects should be interpreted cautiously. Future studies with larger bilingual samples will be critical for determining whether early lexical competition and facilitation effects are genuinely attenuated in bilingual aphasia or were simply difficult to detect under the present task demands. Increasing sample size would also permit more fine-grained analyses of trial-level variability, including comparisons of eye-movement patterns on trials with correct versus incorrect comprehension responses, which may help clarify how online disruption relates to downstream interpretation failures.

Future eye-tracking work could also expand beyond sentence-level manipulations to examine how individual cognitive factors shape online reading behavior in aphasia. Although the present study focused on linguistic variables, prior work suggests that working memory, attentional control, and executive resources may play an important role in supporting sentence comprehension, particularly under conditions of ambiguity or reduced contextual support. Incorporating independent measures of cognitive function would allow future studies to assess how domain-general resources interact with linguistic impairment to influence reading dynamics in bilingual aphasia.

Beyond methodological extensions, the findings from Aim 1 point to important future directions for clinical assessment and intervention. Aim 1.2 demonstrated systematic relationships between spoken and written language impairment across Spanish and English, suggesting that performance in one modality and language can provide meaningful information about the integrity of shared underlying systems. With further empirical validation, these relationships raise the possibility that targeted assessment of spoken or written language skills in one language could inform expectations about performance in the other skill in the same language. This direction is particularly relevant given the absence of standardized guidelines for assessment and treatment planning in bilingual aphasia (Peñaloza et al., 2020; Roberts & Kiran, 2012). Because comprehensive bilingual assessment is time-consuming and resource intensive in clinical settings, identifying principled ways to maximize diagnostic yield from limited testing could substantially improve efficiency without sacrificing validity.

Together, these future directions emphasize the importance of linking clinical profiles, domain-general cognitive resources, and real-time reading behavior to better characterize bilingual reading impairment. Integrating clinical measures of spoken and written language with eye-tracking indices of lexical access and sentence integration would allow future work to identify which aspects of offline impairment predict specific patterns of online disruption. Such an approach would directly inform models like the BIAA by constraining how damage, bilingual experience, and cognitive resources interact to shape reading behavior over time. Clinically, this integration has the potential to support more efficient assessment strategies by identifying when performance in one language or modality can reliably inform expectations about reading ability in the other, thereby improving diagnostic yield in time- and resource-limited settings.

APPENDIX

Appendix 1. Individual Acquired Dyslexia Subtype Classifications in English

Participant	Subtype	Severity	Real							
			Acc	LE	LE_C	LE_p	RE	RE_C	RE_p	SemR
BWA01	Phonological	Mild	1.00	0.16	4.1	< .01	0	-0.73	.48	0
BWA02	Phonological	Mild	0.95	0.15	4.0	< .01	0.11	0.37	.71	0
BWA03	Unimpaired	NA	0.97	0	-0.73	.48	0.07	-0.01	.99	0
BWA04	Unclassified	Moderate	0.77	-0.08	-3.35	.01	0.2	1.24	.25	0
BWA05	Unclassified	Global	0.07	0.06	1.36	.21	0.07	-0.01	.99	0.01
BWA06	Unimpaired	NA	0.87	0.03	0.46	.65	0.14	0.66	.52	0
BWA07	Unimpaired	NA	0.99	0.02	-0.01	.99	-0.01	-0.83	.43	0
BWA08	Phonological	Mild	1.00	0.13	3.2	.01	0	-0.73	.48	0
BWA09	Phonological	Mild	0.97	0.4	11.56	< .001	0	-0.68	0.51	0
BWA10	Phonological	Global	0.21	0.18	4.89	< .01	-0.16	-2.34	0.05	0
BWA11	Deep	Global	0.23	0.15	3.97	< .01	-0.19	-2.61	0.03	0.30
MWA01	Phonological	Mild	0.98	0.11	3.53	< .01	0.05	5.04	< .01	0
MWA02	Phonological	Mild	0.97	0.22	8.14	< .01	0.04	3.98	< .01	0
MWA03	Phonological	Mild	0.96	0.27	10.01	< .01	0.12	13.01	< .01	0
MWA04	Phonological	Mild	0.97	0.2	7.33	< .01	0.07	7.7	< .01	0
MWA05	Phonological	Mild	0.99	0.36	13.63	< .01	-0.01	-1.32	.20	0
MWA06	Phonological	Mild	0.96	0.59	23.1	< .001	-0.01	-1.85	.08	0
MWA07	Unimpaired	NA	0.97	0.01	-0.73	.47	0	-0.79	.43	0
MWA08	Phonological	Mild	0.94	0.41	15.68	< .001	-0.01	-1.32	.20	0
MWA09	Phonological	Mild	0.86	0.52	20.23	< .001	-0.01	-1.85	.08	0
MWA10	Phonological	Mild	0.95	0.35	13.4	< .001	-0.02	-2.92	.01	0
MWA11	Deep	Mild	0.80	0.52	20.06	< .001	0.03	3.45	< .01	0.17

MWA12	Phonological	Mild	0.87	0.56	22.04	< .001	0.04	3.98	< .01	0
MWA13	Unimpaired	NA	0.97	0.07	1.72	.10	0.03	2.92	.01	0
MWA14	Phonological	Mild	1.00	0.14	4.52	< .001	0	-0.26	.79	0
MWA15	Phonological	Mild	0.91	0.46	17.78	< .001	0.02	1.85	.08	0
MWA16	Phonological	Mild	0.97	0.11	3.65	< .01	0.04	3.98	< .01	0
MWA17	Phonological	Mild	0.94	0.41	15.68	< .001	0.13	13.54	< .001	0
MWA18	Unimpaired	NA	0.97	0.05	1.19	.24	0	0.26	.79	0
MWA19	Phonological	Global	0.22	0.15	5.28	< .01	-0.1	-10.89	< .01	0
MWA20	Phonological	Mild	0.96	0.27	10.01	< .01	0.02	1.85	.08	0

Note. *Real Acc* = Proportion correct for all real words; *LE* = Lexicality Effect: Accuracy on real words -Accuracy on nonwords; *LE_C* = Crawford single-subject statistic for the lexicality effect; *LE_p* = p-value associated with lexicality comparison; *RE* = Regularity Effect: Accuracy on regular words – Accuracy on exception words; *RE_C* = Crawford single-subject statistic for the regularity effect; *RE_p* = p-value associated with regularity comparison; *SemR* = Semantic Error Rate. Unclassified = no clear pattern of deficits based on indices and error rates and/or global impairment

Appendix 2. Individual Acquired Dyslexia Subtype Classifications in Spanish

Participant	Subtype	Severity	Real Acc	LE	LE_C	LE_p	SemR	StressR
BWA01	Phonological	Mild	0.98	0.11	5.92	0	0	0.66*
BWA02	Unimpaired	NA	0.99	0.02	0.88	0.4	1	0
BWA03	Surface	Mild	0.93	0	-0.56	0.58	0.09	0.72
BWA04	Surface	Mild	0.92	-0.02	-1.76	0.12	0.07	0.69
BWA05	Phonological	Global	0.17	0.16	8.69	0	0.05	0
BWA06	Phonological	Mild	0.99	0.06	3.15	0.01	0	1
BWA07	Surface	Mild	0.92	-0.01	-1.51	0.17	0	0.64
BWA08	Surface	Mild	0.81	0.07	3.84	0	0	0.42
BWA09	Phonological	Moderate	0.63	0.29	16.45	0	0	0.06
BWA10	Phonological	Moderate	0.76	0.55	31.21	0	0.07	0
BWA11	Deep	Global	0.04	0.04	2.01	0.08	0.15	0

Note. *Real Acc* = Proportion correct for all real words; *LE* = Lexicality Effect: Accuracy on real words -Accuracy on nonwords; *LE_C* = Crawford single-subject statistic for the lexicality effect; *LE_p* = p-value associated with lexicality comparison; *SemR* = Semantic Error Rate; *StressR* = Lexical Stress Rate. *Denotes a stress error rate that is based on fewer than 5 observed errors and was therefore not used for classification. Unclassified = no clear pattern of deficits based on indices and error rates and/or global impairment

Appendix 3. Individual BWA Oral Reading Scores

Participant	Lang	N. Items	Real-Reg	Real-Exc	Real	NW-NH	NW-PH	All NW
BWA01	English	276	1.00	1.00	1.00	0.79	0.91	0.84
BWA02	English	276	0.99	0.87	0.95	0.96	0.89	0.80
BWA03	English	276	1.00	0.92	0.97	0.94	0.95	0.98
BWA04	English	276	0.83	0.62	0.77	0.96	0.87	0.86
BWA05	English	240	0.10	0.02	0.07	0	0.02	0.01
BWA06	English	276	0.92	0.77	0.87	0.86	0.78	0.84
BWA07	English	276	0.99	1.00	0.99	0.94	0.97	0.97
BWA08	English	276	1.00	1.00	1.00	0.73	0.89	0.87
BWA09	English	276	0.98	0.97	0.97	0.28	0.85	0.57
BWA10	English	93	0.13	0.30	0.21	0.20	NA	0.03
BWA11	English	240	0.18	0.37	0.23	0	0.17	0.08
BWA01	Spanish	316	NA	NA	0.98	0.84	0.95	0.87
BWA02	Spanish	316	NA	NA	0.99	0.84	0.97	0.97
BWA03	Spanish	316	NA	NA	0.93	0.88	0.93	0.94
BWA04	Spanish	316	NA	NA	0.92	0.03	0.93	0.95
BWA05	Spanish	280	NA	NA	0.17	0	0.02	0.01
BWA06	Spanish	316	NA	NA	0.99	0.86	1.00	0.93
BWA07	Spanish	316	NA	NA	0.92	0.71	0.93	0.94
BWA08	Spanish	316	NA	NA	0.81	1.00	0.74	0.74
BWA09	Spanish	316	NA	NA	0.63	0.96	0.40	0.34
BWA10	Spanish	113	NA	NA	0.76	0	NA	0.20
BWA11	Spanish	280	NA	NA	0.04	0.32	0	0

Note. Administration of some oral reading activities across participants was discontinued due to task difficulty or participant request. The maximum possible number of items across English is 276 and Spanish is 316. *NA* = Not administered; *Lang* = Language; *N. Items* = Total Number of Items completed; *Real-Reg* = proportion correct on regularly spelled words; *Real-Exc* = proportion correct on exception spelled words; *Real* = total proportion correct on all real words; *NW-NH* = proportion correct on nonhomophonic nonwords; *NW-PH* = proportion correct on pseudohomophones; *All NW* = total proportion correct on all nonwords

Appendix 4. Individual BWA Reading Comprehension Scores

Participant	Lang	N. Items	Words	N. Items	Sentences
BWA01	English	40	1.00	40	0.97
BWA02	English	40	1.00	40	1.00
BWA03	English	40	0.97	40	0.92
BWA04	English	40	0.77	40	0.70
BWA05	English	40	0.70	40	0.25
BWA06	English	40	1.00	40	0.67
BWA07	English	40	1.00	40	1.00
BWA08	English	40	1.00	40	1.00
BWA09	English	40	0.95	40	0.90
BWA10	English	40	0.97	40	0.70
BWA11	English	40	0.75	40	0.55
BWA01	Spanish	40	0.87	40	0.82
BWA02	Spanish	40	0.97	40	0.90
BWA03	Spanish	40	0.80	40	0.65
BWA04	Spanish	40	0.87	40	0.70
BWA05	Spanish	40	0.80	40	0.32
BWA06	Spanish	40	0.97	40	0.70
BWA07	Spanish	40	0.92	40	0.95
BWA08	Spanish	40	0.95	40	0.85
BWA09	Spanish	40	0.82	40	0.70
BWA10	Spanish	40	1.00	40	0.65
BWA11	Spanish	40	0.80	40	0.50

Note. *Lang* = Language; *N. Items* = Total number of items completed; *Words* = proportion correct on word-picture-matching task; *Sentences* = proportion correct on sentence-picture-matching task

Appendix 5. Individual BWA Semantic Scores

Participant	Lang	N. Items	SWPM	N. Items	SSPM
BWA01	English	40	0.97	40	0.87
BWA02	English	40	1.00	40	0.90
BWA03	English	40	1.00	40	0.90
BWA04	English	40	0.85	40	0.42
BWA05	English	40	0.72	40	0.47
BWA06	English	40	1.00	40	0.60
BWA07	English	40	1.00	40	1.00
BWA08	English	40	1.00	40	1.00
BWA09	English	40	0.95	40	0.80
BWA10	English	40	0.95	40	0.67
BWA11	English	40	0.75	40	0.55
BWA01	Spanish	40	0.87	40	0.42
BWA02	Spanish	40	1.00	40	0.92
BWA03	Spanish	40	0.75	40	0.57
BWA04	Spanish	40	0.92	40	0.45
BWA05	Spanish	40	0.77	40	0.52
BWA06	Spanish	40	0.97	40	0.62
BWA07	Spanish	40	0.95	40	0.90
BWA08	Spanish	40	0.95	40	0.85
BWA09	Spanish	40	0.90	40	0.67
BWA10	Spanish	40	1.00	40	0.90
BWA11	Spanish	40	0.82	40	0.47

Note. *Lang* = Language; *N. Items* = Total number of items completed; *SWPM* = proportion correct on spoken word-picture-matching task; *SSPM* = proportion correct on spoken sentence-picture-matching task.

Appendix 6. Individual BWA Phonological Processing Scores

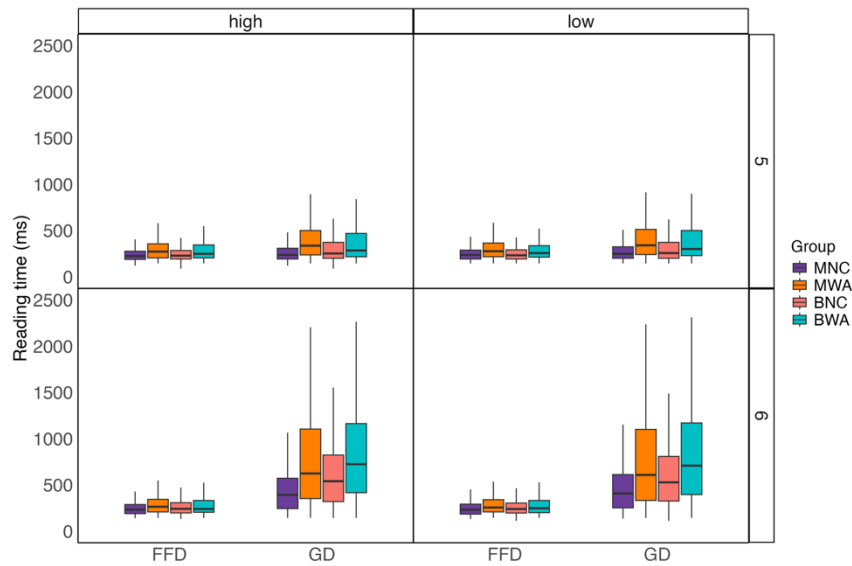
Participant	Lang	N. Items	ALD-RW	ALD-NW	Rep-RW	Rep-NW	SDel	RJ
BWA01	English	245	0.97	0.92	0.97	0.82	0.76	0.78
BWA02	English	245	0.97	0.85	0.97	0.65	0.76	0.93
BWA03	English	245	0.90	1.00	0.97	0.67	0.68	0.91
BWA04	English	245	0.75	0.85	0.92	0.72	0.60	0.78
BWA05	English	245	0.65	0.87	0.82	0.57	0	0.53
BWA06	English	245	0.87	0.87	0.85	0.65	0.28	0.83
BWA07	English	245	1.00	0.95	1.00	0.85	1.00	1.00
BWA08	English	245	1.00	1.00	1.00	0.87	0.84	1.00
BWA09	English	245	0.97	0.80	0.97	0.82	0.36	0.96
BWA10	English	220	0.87	0.82	0.50	0.17	NA	0.63
BWA11	English	245	0.85	0.82	1.00	0.77	0.12	0.86
BWA01	Spanish	225	0.80	0.87	1.00	0.82	0.88	0.77
BWA02	Spanish	225	1.00	0.97	0.95	0.67	0.84	0.95
BWA03	Spanish	225	0.82	0.92	0.80	0.57	0.60	0.67
BWA04	Spanish	225	0.75	0.92	0.87	0.70	0.68	0.52
BWA05	Spanish	225	0.60	0.97	0.90	0.65	0	0.72
BWA06	Spanish	225	0.95	0.92	0.97	0.85	0.80	0.75
BWA07	Spanish	225	0.80	0.95	0.87	0.90	1.00	0.95
BWA08	Spanish	225	0.90	0.67	0.90	0.65	0.52	0.95
BWA09	Spanish	225	0.80	0.70	0.85	0.65	0.32	0.92
BWA10	Spanish	200	0.90	0.92	0.97	0.40	NA	0.60
BWA11	Spanish	225	0.85	0.77	0.82	0.47	0.12	0.77

Note. Administration of some oral reading activities across participants was discontinued due to task difficulty or participant request. The maximum possible number of items across English is 245 and Spanish is 225. *NA* = Not administered; *Lang* = Language; *N. Items* = Total Number of Items completed; *ALD-RW* = proportion correct auditory lexical decision for real words; *ALD-NW* = proportion correct on auditory lexical decision for nonwords; *Rep-RW* = proportion correct on repetition of real words *Rep-NW* = proportion correct on repetition of nonwords; *SDel* = proportion correct on sound deletion; *RJ* = proportion correct on rhyme judgment task

Appendix 7. ENC Demographic Characteristics

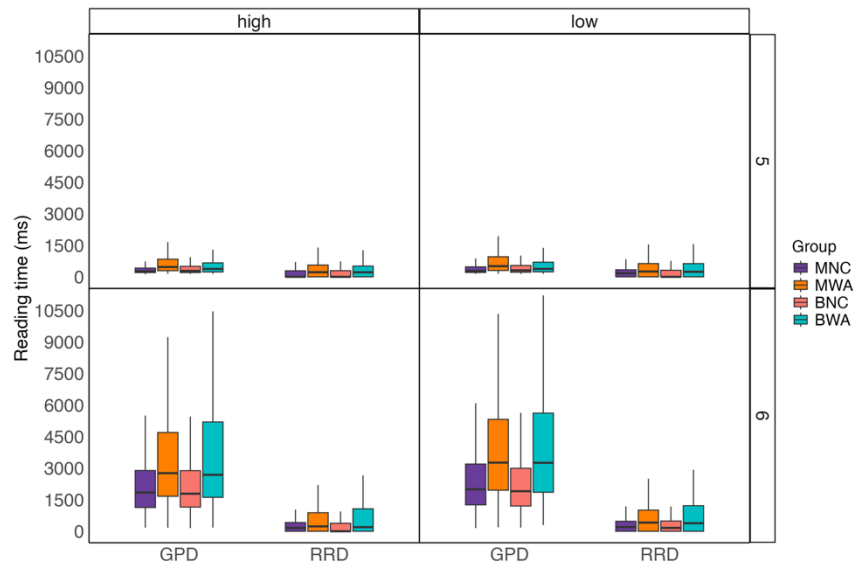
ID	Sex	Age	Edu	Race	Ethnicity
ENC01	M	27	20	White	Non-Hispanic
ENC02	F	21	15	White	Non-Hispanic
ENC03	F	21	15	White	Non-Hispanic
ENC04	F	22	14	White	Non-Hispanic
ENC05	F	20	14	White	Non-Hispanic
ENC06	F	20	14	Asian	Non-Hispanic
ENC07	F	21	15	White	Non-Hispanic
ENC08	F	20	14	Asian & White	Non-Hispanic
ENC09	M	21	15	White	NR
ENC10	M	24	16	White	Non-Hispanic
ENC11	F	18	12	Asian	Non-Hispanic
ENC12	F	22	15	White	Non-Hispanic
ENC13	F	21	15	White	Non-Hispanic
ENC14	F	19	13	Asian	Non-Hispanic
ENC15	F	24	18	Asian	Non-Hispanic
ENC16	F	21	14	White	Non-Hispanic
Black or African					
ENC17	F	25	17	American	Non-Hispanic
ENC18	M	21	15	Asian	Non-Hispanic
ENC19	F	20	14	White	Non-Hispanic
ENC20	F	21	15	Asian	Non-Hispanic
Mean		21.4	15.0		
SD		2.1	1.7		

Appendix 8. Early-Stage Processing Measures by Group, Area of Interest, and Constraint



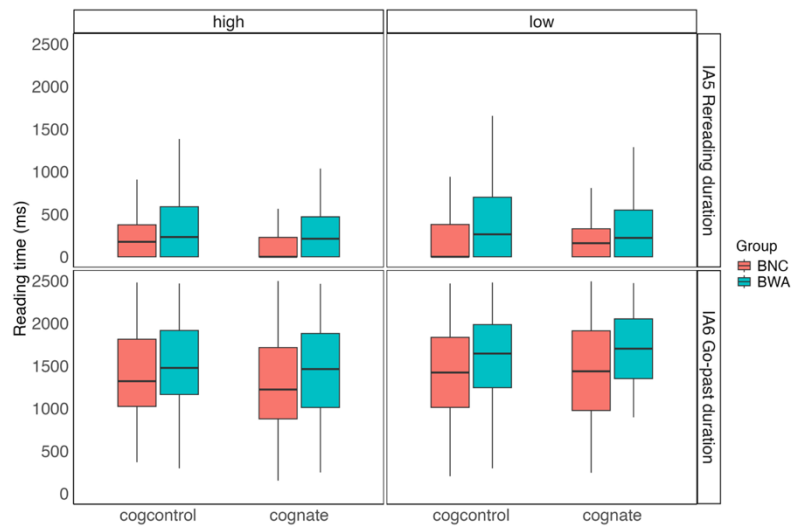
Caption. Reading time distributions for early-stage measures, first fixation duration (FFD) and gaze duration (GD) across monolingual and bilingual groups, shown separately by interest area (facets on the right) and semantic constraint. Main effects of group (aphasia vs. controls) are primarily shown. Interest area 5 denotes the target word, e.g., ‘piano’ while interest area 6 denotes a prepositional phrase, considered the spillover region.

Appendix 9. Late-Stage Processing Measures by Group, Interest Area, and Constraint



Caption. Reading time distributions for late-stage measures, go-past duration (GPD) and rereading duration (RRD) across monolingual and bilingual groups, shown separately by interest area (facets on the right) and semantic constraint. Main effects of group (aphasia vs. controls) are primarily shown. Interest area 5 denotes the target word, e.g., ‘piano’ while interest area 6 denotes a prepositional phrase, considered the spillover region.

Appendix 10. Cognate Facilitation Effects Among Bilingual Participants



Caption. Distribution of reading times for cognate and control stimuli by group, semantic constraint, and area of interest. Values reflect back-transformed estimates from log-transformed reading time models. Boxplots are shown to illustrate variability in reading behavior across conditions and complement the model-based analyses reported in the main text.

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