Phonological, Semantic and Root Activation in Spoken Word Recognition in Arabic: Evidence from Eye Movements

by

Abdulrahman Alamri

Thesis submitted to the
Faculty of Graduate and Postdoctoral Studies
In partial fulfillment of the requirements
For the Ph.D. degree in Linguistics

Thesis supervisor

Tania S. Zamuner

Department of Linguistics
Faculty of Arts
University of Ottawa

Abstract

Three eyetracking experiments were conducted to explore the effects of phonological, semantic and root activation in spoken word recognition (SWR) in Saudi Arabian Arabic. Arabic roots involve both phonological and semantic information, therefore, a series of three studies were conducted to isolate the effect of the root independently from phonological and semantic effects. Each experiment consisted of a series of trials. On each trial, participants were presented with a display with four images: a target, a competitor, and two unrelated images. Participants were asked to click on the target image. Participants' proportional fixations to the four areas of interest and their reaction times (RT) were automatically recorded and analyzed. The assumption is that eye movements to the different types of images and RTs reflect degrees of lexical activation. Experiment 1 served as a foundation study to explore the nature of phonological, semantic and root activation. Experiment 2A and 2B aimed to explore the effect of the Arabic root as a function of semantic transparency and phonological onset similarity. Growth Curve Analyses (Mirman, 2014, GCA;) were used to analyze differences in target and competitor fixations across conditions. Results of these experiments highlight the importance of phonological, semantic and root effects in SWR in Arabic. Fixations to competitors were graded and corresponded to the different amounts of phonological, semantic and morphological overlap between targets and competitors. The results of this work highlight the importance of the Arabic consonantal root as an independent processing unit in lexical access in SWR in Arabic that is separable from phonological and semantic units of processing. Finally, the results of this work provided support to models of SWR that feature both whole-word processing as well as morphological decomposition (e.g. Baayen, Dijkstra, & Schreuder, 1997; Giraudo & Grainger, 2000; Schreuder & Baayen, 1997). They also provide support to the morpheme-based theory of Arabic morphology (McCarthy, 1979, 1981).

Acknowledgements

Although only my name appears on the title page of this dissertation, it is a product of a collective influence, both professional and personal, on me of so many amazing people who have crossed my path.

First and foremost, I want to express my deepest gratitude to my supervisor Tania Zamuner. Thank you for your guidance, inspiration and support throughout these years. Thank you for always being available, for reading everything no matter how last minute I sent it, and for all your time and patience.

I am also grateful to Adam Ussishkin, Laura Sabourin, Elena L Valenzuela, and Kevin McMullin for agreeing to be on my committee and for their valuable comments. Thank you for sharing your expertise and knowledge with me. Thank you also to the current and previous professors of the department of linguistics who have impacted my education during the last seven years in the best ways possible.

I would be remiss if I did not also thank all the participants in this study who willingly gave of their time. Your contribution made this work possible and is tremendously appreciated. Special thanks go to Majed Alshehri and Saad Alkarni for recording and rerecording my stimuli so many times. I would also like to thank Fayzah alshammari and Rajaa Debab for their help in testing participants.

Most of all, I am endlessly grateful to my beloved family who have given me unconditional love, support and encouragement throughout the PhD program. Special thanks go to my mother, the light of my life and the aroma of heaven. To my wife, *Alia Alamri*, and my lovely kids *Shadin, Jawad, Loubna, and Ussem*, thank you very much for your inspiration and support. I love you.

Dedication

THIS THESIS IS DEDICATED TO

MY MOTHER

AND

MY FATHER
MAY GOD BLESS HIS SOUL

Table of Contents

List of Tables

List of Figures

Chapter 1

Introduction

During the 1960s and 1970s, research on word recognition was primarily focused on the visual modality and several models of word recognition were developed based on data obtained from reading studies (e.g., Forster, 1976, 1979; Morton, 1969) to describe the processes and mechanisms of visual word recognition (VWR) (Frauenfelder & Tyler, 1987). During that time, speech perception research was focussed on the discrimination and categorization of phonetic segments and trying to understand how physical acoustic signals are mapped onto phonetic segments (Frauenfelder & Tyler, 1987). However, in the 1980s, psychologists, linguists and neuroscientists began to study this process within a larger context, namely the lexical processing system (Cohen, 1986; Frauenfelder & Tyler, 1987; Jusczyk & Luce, 2002; Vaissiere, 1986) and a number of models were developed for spoken word recognition (SWR) (e.g., Elman & McClelland, 1983; Marslen-Wilson & Tyler, 1980; Marslen-Wilson & Welsh, 1978). The development of models specific to SWR was driven by the fact that speech, unlike written text, is highly variable, transitory and continuous with no clear boundaries between words (Vaissiere, 1986; Weber & Scharenborg, 2012).

Since then, research on SWR has been attempting to develop a theory of SWR that describes the complicated mental mechanisms that transform acoustic input into recognizable linguistic units. Although there is no consensus among researchers on the mechanisms involved in the process of SWR, key findings about the representations and processes involved in SWR have been obtained (Frauenfelder & Tyler, 1987; Jusczyk & Luce, 2002; Weber & Scharenborg, 2012). Based on these findings, several models of SWR have been suggested, including the cohort model (Marslen-Wilson & Welsh, 1978); the TRACE model (McClelland & Elman, 1986); the shortlist models (A and B) (Norris, 1994; Norris & McQueen, 2008); the neighborhood activation model (NAM, Luce & Pisoni, 1998); and the distributed cohort model (DCM, Gaskell & Marslen-Wilson, 1997), among others (further details of these models are discussed in Chapter 3).

Numerous empirical studies using different methodologies have found evidence for different variables having an effect on the process of SWR, including those central to this dissertation: phonological variables (e.g., Allopenna, Magnuson, & Tanenhaus, 1998; Marslen-Wilson & Zwitserlood, 1989; Slowiaczek, Nusbaum, & Pisono, 1987), semantic variables (e.g., Apfelbaum, Blumstein, & McMurray, 2011; Mirman & Magnuson, 2009; Yee & Sedivy, 2006) and morphological variables (e.g., Baayen & Schreuder, 1999; Caramazza, Laudanna, & Romani, 1988; Cutler & Norris, 1988; Rastle & Davis, 2008; Taft, 1981; Taft & Forster, 1975; Tyler, Marslen-Wilson, Rentoul, & Hanney, 1988). Other variables include lexical frequency, neighbourhood density and contextual cues.

These findings have been mainly based on data obtained from Indo-European languages, which constitute only a subset of the languages of the world, and hence might not accommodate all the variables and lexical properties found in other languages. The internal structure of words in Indo-European languages, such as English, for instance, is linear at the phonetic, morphemic and syllabic levels. A word consists of one or more morphemic units which contain sequences of segments that carry both phonological and semantic contents. When a word has more than one morphemic unit, these morphemic units are linearly joined (e.g., *un-employ-ment*). This differs from Semitic languages such as Arabic, which have a non-linear morphological system. According to the morpheme-based theory of Arabic morphology (e.g. McCarthy, 1979, 1981), which is the dominant theory of Arabic morphology, a word in Arabic is constructed non-linearly by combining a consonantal root that conveys the general thematic meaning (e.g., [ktb] 'writing') and a pattern that conveys morpho-syntactic information (e.g., the past tense pattern: *CaCaC*) producing the word (*katab* 'wrote'). An alternative theory is the stem-based theory, which claims that words are derived from the stem forms of the imperfective verb (Benmamoun, 1999, 2003; Ratcliffe, 1997).

Previous research on both spoken and visual word recognition in Arabic (Boudelaa & Marslen-Wilson, 2000, 2001, 2004, 2005, 2011, 2015; Mahfoudhi, 2005; Qasem, 2010; Ussishkin et al., 2015) and in Hebrew (Deutsch et al., 1998; Frost, Deutsch, Gilboa, Tannenbaum, & Marslen-Wilson, 2000; Frost et al., 1997) has provided evidence for the existence of morphological processing in which words that share the same root or pattern with a spoken or written word are activated. These studies have found evidence for the effects of both the root and the pattern; however, the effect of word patterns has been found to be less robust. This can be attributed to the large number of patterns in Semitic languages, which makes using the pattern as a cue to lexical activation less economic and effective. The pattern is a template with which thousands of roots interleave to create thousands of words with different phonological and semantic properties. The root, on the other hand, consists of two, three, or four consonants that can interleave with a limited number of patterns creating a short list of words that have phonological and semantic properties in common and this, in my opinion, is why the root can be an effective cue in word recognition. Therefore, the current work limits the investigation of morphological effect in SWR in Arabic to the consonantal root.

Most of the studies that have investigated SWR (Boudelaa & Marslen-Wilson, 2000, 2015; Ussishkin et al., 2015) and VWR in Arabic (e.g., Boudelaa & Marslen-Wilson, 2001, 2004, 2005; Mahfoudhi, 2005; Qasem, 2010) have found strong and robust priming effects of the root in word recognition and concluded that root priming in Arabic is the result of an independent morphological process that decomposes the word into its morphemic units (root and pattern) and that the root is a lexical representation that can facilitate lexical access. However, Abu-Rabia and Awwad (2004) did not find a facilitatory priming effect for the root. Therefore, the current work aims to test these findings and investigate the timecourse of the root in SWR in Arabic using eye tracking, a methodology that has not been used before to explore SWR in Arabic. The current work also investigates whether there is evidence in favour of either the full-listing models or the decompositional models (full-parsing models and dual-route models, respectively). Lastly, several studies (e.g., Boudelaa & Marslen-Wilson, 2000, 2001, 2015; Mahfoudhi, 2005) have found that the priming effect of the root is not dependant on the semantic transparency between the target and the prime. These findings are tested in Experiment 2 of the present work, in which root activation is investigated as a function of semantic transparency. In addition, Experiment 2 addresses whether root activation is a function of phonological overlap between the target and competitors.

To summarize, there are three goals in the present dissertation. First, the current work aims to use the visual world paradigm with eye tracking to explore the nature of phonological, semantic and root activation in SWR in Arabic. The second goal is to test validity of two competing theories of Arabic morphology: the morpheme-based theory and the stem-based theory, and by extension the full listing models against the decompositional models of complex word recognition. The last goal of this work is to investigate whether the root effect is dependent on the amount of semantic and phonological overlaps between targets and competitors.

This dissertation is organized as follows: Chapter 2 provides a short introduction on the phonology and morphology of Arabic. It also covers the background regarding the different theories of Arabic morphology and its implication for SWR. Chapter 3 reviews the theoretical literature regarding SWR, the different models of SWR and previous empirical research on SWR. Chapter 4 presents Experiment 1, which is a foundation study for the investigation of phonological, semantic and root activation in SWR in Arabic. Chapter

5 summarizes Experiment 2, which tested the effect of the Arabic consonantal root and whether the effect varies based on the amounts of the semantic and/or phonological overlap between words. Chapter 6 is the general discussion and conclusion.

Chapter 2

Arabic Phonology and Morphology Implications for the study of SWR in Arabic

The purpose of this chapter is to present the theoretical issues related to this dissertation. The first part of this chapter provides an introduction about Arabic phonology and describes the consonants and vowels of the Modern Standard Arabic spoken in Saudi Arabia which is the focus of this work. The second part deals with Arabic derivational and inflectional morphology. It also discusses the main theories of Arabic morphology, namely the morpheme-based and the stem-based theories. The third part of this chapter reviews empirical studies from a variety of fields that have found cognitive evidence for the Arabic root. Finally, the chapter ends with a discussion of the implications of the theories of morphology and the status of the root as a morphological processing unit.

2.1 Arabic Phonology

Arabic is a Semitic language spoken by about 190 million people all over the world and is the official language of more than 17 countries in the Middle East and North Africa (Newman, 2002; Watson, 2007). There are hundreds of Arabic dialects that differ from one another and from Classical Arabic (CA) found in the Holy Quran and other religious and literary texts. Modern Standard Arabic (MSA) is the language of press, media, official speeches and most modern publications. MSA has twenty-eight consonants that vary in their places and manners of articulation (in Table 2.1 below).

	Bilabial	Labiodentals		Interdental		Dental		Pharyngealized Dentals		Alveolar	Palatal	Velar		Uvular	Pharyngeal		Glottal
Voicing		−	+	−	+	−	+	−	+			−	+		−	+	
Stop	b ب					t ت	d د	ṭ ط	ḍ ض			k ك		q ق			ʔ ء
Fricative		f ف		θ ث	ð ذ	s س	z ز	ṣ ص	ð̣ ظ		ʃ ش	x خ	ɣ غ		ħ ح	ʕ ع	h ه
Affricate											dʒ ج						
Trill										r ر							
Lateral										l ل							
Nasal	m م									n ن							
Semi-Vowel	w و										j ي						

Table 2.1: The consonant inventory of MSA in IPA transcription and Arabic orthographic forms (Adapted from Aljumah, 2008).

All these consonants, vowels and diphthongs are maintained in the MSA spoken in Saudi Arabia; however, some consonants and vowels vary in the regional dialects of Saudi Arabia. For example, the consonant /k/ is palatalized into /ʧ/in the eastern province dialects and into /ts/ in Najdi dialects. In these dialects, /k/ palatalization is triggered by adjacent short or long vowel /i/ and is pronounced /k/ otherwise. Other consonants that vary in regional dialects are those such as the voiced pharyngealized dental fricative /ðˤ/, which is pronounced as /zˤ/ in Hijazi dialects. However, these variations have no effect on the experiments as all the participants reported that they do not produce these alternations in their speech or encounter them regularly in their daily life (this is discussed in more detail in the Methodology section of Chapter 4).

MSA has three short vowels (/a/, /i/ and /u/) and three long vowels (/a:/, /i:/ and /u:/). In addition, Arabic has two diphthongs (/aj/ and /aw/). All these vowels and diphthongs are present in the MSA and the regional dialects spoken in Saudi Arabia. The long vowels are represented in letters in Arabic orthography, whereas short vowels are represented in diacritics. The diacritics of the short vowels are only used in religious and some educational textbooks for young learners, and are not used generally in the press or other publications.

There are some key features of the phonological rules that are relevant for the current research (an exhaustive description of Arabic phonology is beyond the scope of this dissertation; see (Bateson, 2003; Holes, 2004; McCarthy & Prince, 1990b; Watson, 2007; Wright, 1967) for further discussion). Arabic words and syllables must begin with consonants and not vowels. Moreover, a maximum of two consonant clusters are allowed word-medially and word-finally; however, consonant clusters are not allowed word-initially (McCarthy & Prince, 1990b; Ryding, 2005). MSA allows five types of syllable structures, namely weak structure CV (weak), CVV (strong), CVC (strong), CVVC (super-strong) and CVCC (super-strong). With regard to stress, the final syllable is never stressed unless it is a super-strong structure (CVVC or CVCC). Stress is always on the penult; however, if the penult is a weak syllable, the stress goes to the antepenult (Ryding, 2005). In this dissertation, the number of syllables and stress pattern of the stimuli used were partially matched (more details are discussed in the methodology section of 4). To sum up, this section discussed some features of Arabic phonology that provide a general picture of the sound structure of the language. The next section provides a general discussion of Arabic morphology followed by a discussion of theories of Arabic morphology.

2.2 Arabic Morphology

The major characteristic of Arabic morphology (and other Semitic languages) is that it is based on the root and pattern morphology. Therefore, the Arabic word can be broken down into a root and a pattern. Ryding (2005) defines a root as follows:

> "...a relatively invariable discontinuous bound morpheme, represented by two to five phonemes, typically three consonants in a certain order, which interlocks with a pattern to form a stem and which has lexical meaning" (p. 47).

The root may consist of 2, 3, 4 or 5 consonants; however, the majority of Arabic roots consist of three consonant (Ryding, 2005; Watson, 2007). These roots are not pronounceable unless they interleave with patterns. The pattern, on the other hand, is a template that has fixed positions for vowels and other vacant positions that can be occupied by the consonants of the root. Besides the fixed vowels, some patterns have added consonants as well. Ryding (2005) defines a pattern as follows:

> "...a bound and in many cases, discontinuous morpheme consisting of one or more vowels and slots for root phonemes (radicals), which either alone or in combination with one to three derivational affixes, interlocks with a root to form a stem, and which generally has grammatical meaning" (p. 48).

The two main procedures for word formation are derivation and inflection. Derivational morphology is a morphological process by which new words are created. These derived words are semantically different from the source words from which they are derived. Part of speech of the derived words may or may not differ from that of the source forms. Therefore, verbs can be derived from nouns, nouns can be derived from verbs and adjectives can be derived from nouns etc. (Bauer, 2002; Bickel & Nichols, 2007). Inflectional morphology, on the other hand, is a morphological process applied to a word to satisfy the grammatical functions required by the environment in which that word occurs. These grammatical functions include case assignment and agreement in gender, person, and number (Bickel & Nichols, 2007). Furthermore, unlike derived words, inflected words do not differ from base words in terms of semantic features and part of speech (Bauer, 2002; Bickel & Nichols, 2007). Therefore, the stem of an Arabic derived word is formed based on derivational morphological rules that combine the consonantal root and the pattern template. Inflectional affixes can then be added to Arabic stems and can also provide information on number, gender and person (Watson, 2007). As the Arabic words used in this dissertation are all nouns, the rest of this discussion will focus on the morphology of nouns. The next section will introduce the different types of nouns in Arabic. It also describes the derivational and inflectional morphology of Arabic nouns.

2.2.1 Noun Morphology

There are two types of nouns in Arabic: primitive and derived. Primitive nouns are "nouns that are not verbal derivatives and that may function syntactically only as substantives and not adjectives" (Holes, 2004, p. 155). These nouns are mainly nouns denoting elements of nature, animals and parts of the body. Primitive nouns do not share roots with other words. See example 2.1 from (Ryding, 2005, p. 92).

(2.1) (a) **fahd** "cheetah"

(b) **rajul** "man"

(b) **ʕayn** "eye"

(c) **yawm** "day"

Derived nouns, on the other hand, are nouns that share their roots with other words and are from verbal or other noun forms (Wright, 1967, p. 92). Derived nouns are divided into two types: deverbal and denominative. Deverbal nouns are derived from verbal roots and denominative nouns are derived from nouns. Wright (1967) defines six types of denominative nouns and 44 types of deverbal nouns in CA. Both derived and primitive nouns are inflected in Arabic to indicate case, determination, gender, number or person. Note that most of the stimuli used in this dissertation were derived nouns. However, some primitive nouns were used as phonological or unrelated distractors. Nouns derived by affixation were used as target words in Experiment 2B and were paired with root competitors that did not have these added affixes. This design was used to determine whether the effect of the root can still be obtained even if the onsets are different.

2.2.2 Noun Derivation

There are two types of noun derivation in Arabic: by shifting vowel patterns and by affixation (Bateson, 2003). Noun derivation by switching vowel patterns occurs when one of the shortest patterns allowed by the system (CaCC, CiCC or CuCC) is augmented by adding vowels or lengthening vowels and/or consonants to impose new patterns with new morpho-syntactic contributions to the meaning. This is shown in example 2.2 below:

(2.2) (a) [drs] + CaCC = **dars** "lesson"

(b) [drs] + CaCaC = **daras** "studied'

(c) [drs] + Ca:CiC = **da:ris** "student"

(d) [drs] + CuCu:C = **duru:s** "lessons"

Looking at example 2.2, we can see that adding vowels creates different patterns. In (a) when the root [**drs**] interleaves with the pattern *CaCC*, the resulting word is *dars* 'lesson,' which is a noun, whereas in (b) when the same root interleaves with the augmented pattern *CaCaC*, the word becomes *daras*, which is a verb in the past tense. In (c), when the pattern *Ca:CiC* is occupied by the root [**drs**], it gives the agentive form *da:ris*. Finally, in (d) the pattern *CuCu:C*, which is often used to form a broken plural, interleaves with the same root to produce the plural form *duru:s* 'lessons'.

The second type of noun derivation is derivation by affixation, this happens when some affixes (fixed consonants and vowels) such as [**ma**], which indicates the time or place of action, [**mi**], which indicates an instrument, [**mu**], which indicates doer of an action (the agent) or [**ta**], which indicates that an interactive action is added to the pattern of the imperfect verb to impose new ones with different meanings. As you can see in example 2.3, the pattern *maCCaCah* in (a) contains a fixed [**ma**] at the initial position (the suffix **-ah** is an inflectional morpheme for feminine). Thus, when the root [**drs**] interleaves with this pattern, the resulting word is *madrasah* 'school' which is a noun that indicates a place of action. In (b) the pattern contains the prefix [**mu**], which produces the agentive form *mudarris* 'teacher'. Finally, with the prefix [**ta**], the resulting noun is *tadarus* which indicates the interactive action of discussing a topic.

(2.3) (a) [**drs**] + maCCaCah = **madrasah** 'school'

(b) [**drs**] + muCaCCiC = **mudarris** 'teacher'

(b) [**drs**] + taCaCuC = **tadarus** 'discussing'

Noun derivation by switching vowel patterns and by affixation results in numerous morphological structures denoting different semantic functions. Holes (2004) provides examples of these morphological structures (patterns) that produce nouns with different semantic functions such as instance nouns, nouns of manner, nouns of place and time, nouns of instrument and nouns of profession, among others (pp. 155–162). In addition to noun derivation, Arabic has a noun inflectional system that adds affixes to the Arabic stem. That is, inflection takes place after derivation because the stem is formed by derivation. The following section briefly describes noun inflection in Arabic.

2.2.3 Noun Inflection

Nouns are inflected in Arabic to indicate case, determination, gender, number or person (Bateson, 2003, p. 9).[1] This is performed by adding suffixes to nouns. The three suffixes **-u**, **-a** and **-i** are case markers that are added to nominative, accusative and agentive nouns, respectively. When a noun is indefinite, nunation is added to these suffixes and they become **-un**, **-an** and **-in**. Look at example 2.4 below and note that the definite nouns are preceded by the definite article *al* and thus nunation is not added. In example 2.5, the noun *ka:tib* is indefinite, and hence the case marker and the nunation are added to indicate both case and definiteness.

(2.4) (a) alka:tib***u*** [Def. Masc. NOM] 'the writer'

(b) alka:tib***a*** [Def. Masc. ACC] 'the writer'

(c) alka:tib***i*** [Def. Masc. GEN] 'the writer'

(2.5) (a) ka:tib***un*** [Indef. Masc. NOM] 'a writer'

(b) ka:tib***an*** [Indef. Masc. ACC] 'a writer'

(c) ka:tib***in*** [Indef. Masc. GEN] 'a writer'

With regard to number in noun inflection, dual nouns (nouns representing two people or objects) are formed by adding the suffix **-a:n** and by adding the suffix **-ajn** in the accusative and genitive cases. Regular plural are formed by adding the suffix **-u:n** in the nominative case and the suffix **-i:n** in the accusative and genitive cases. Finally, to inflect the singular feminine nouns, the suffixes **-ah** and **-a:t** are added to the masculine plural to create the singular feminine and regular feminine plural forms. See example 2.6 below.

(2.6) (a) ka:tib***a:n*** [Indef. Masc. Nom. Dual] 'two writers'

[1] Please note that person is not discussed here since it is limited to verb inflection.

(b) ka:tib***ajn*** [Indef. Masc. Acc. or Gen. Dual] ‘two writers’

(c) ka:tib***u:n*** [Indef. Masc. Nom.] ‘writers’

(d) ka:tib***i:n*** [Indef. Masc. Acc. or Gen. Plural] ‘writers’

(e) ka:tib-***ah*** [Indef. Fem. Singular] ‘a female writer’

(e) ka:tib-***ata:n*** [Indef. Fem. Acc. or Gen. Dual] ‘two female writers’

(e) ka:tib-***atajn*** [Indef. Fem. Nom. Dual] ‘two female writers’

(f) ka:tib-***a:t*** [Indef. Fem. Plural] ‘female writers’

For the stimuli used in this dissertation, all of the items were singular. No inflected forms were used except a few feminine words that received the feminine suffix **-ah** such as *sajjar**ah*** ‘car’. Inflected forms were not used in order to limit the morphological effect to the two abstract morphemes of the root and pattern as much as possible.

The discussion above provided an overview of noun morphology to provide a general picture of the internal structure of Arabic words. In addition, these features of Arabic morphology were taken into account when choosing stimuli. The next section discusses the main theories of Arabic morphology and their implications for the mechanisms involved in SWR in Arabic.

2.3 Theories of Arabic Morphology

The discussion provided above on the root and pattern morphology of Arabic is laid out in the work of the old Arab grammarians since the work of Sibawaih.[2] in the 8th century and it is still popular among modern Arab grammarians today (Mahfoudhi, 2005). This view of Arabic morphology is often referred to as the classical (or traditional) theory of

[2]Sibawaih is considered the greatest Arabic linguist. He was a Persian who lived in Iraq in the 8th century AD. His treatise *Alkita:b* ‘the book’ is the oldest Arabic language grammar book. It covers various topics in phonetics, phonology, word structure and sentence structures among other concepts (Al-Nassir, 1993).

Arabic morphology (Mahfoudhi, 2005; Qasem, 2010). It is also adopted by some modern linguists (e.g., Cantineau, 1950). However, the classical theory of Arabic morphology only lists the different word patterns, their morpho-syntactic and semantic functions, and how these patterns interleave with roots to create words with different denotations.

The next section describes the two most prominent theories of Arabic morphology (and Semitic by extension). These are the morpheme-based theories and the stem-based theories.[3]

2.3.1 Morpheme-Based Theory

The morpheme-based theory has undergone two main phases: the CV morphology hypothesis (McCarthy, 1979, 1981) and the prosodic morphology hypothesis (McCarthy & Prince, 1990b). These two hypotheses are briefly discussed below.

2.3.1.1 CV morphology hypothesis

Influenced by autosegmental phonology Goldsmith (1976a, 1976b), McCarthy (1981) developed the CV-morphology hypothesis, which is based on root and pattern morphology but breaks down the pattern into three tiers: CV skeleton, vowel melody and affixal consonant (if applicable). For example, the word *ka:tibah* 'female writer' consists of the consonantal root [**ktb**], the vowel melody **a-i**, the CV-skeleton **CVCVCVC** and the feminine suffix **-ah**. According to McCarthy (1981), the root carries the general thematic meaning of the word, the vowel melody carries syntactic information, such as aspect and voice, and the CV skeleton is a placeholder for the surface form of the word that accounts for the morphological shape invariance (see example 2.1). Note that the analysis of McCarthy (1981) focuses on the Arabic verbal system; however, the same analysis can be applied to Arabic nouns.

[3]The etymon and the phonetic matrix theories are other theories of Arabic morphology. For more discussion of these theories, please see Bohas (1997, 2000); Bohas and Guillaume (1984).

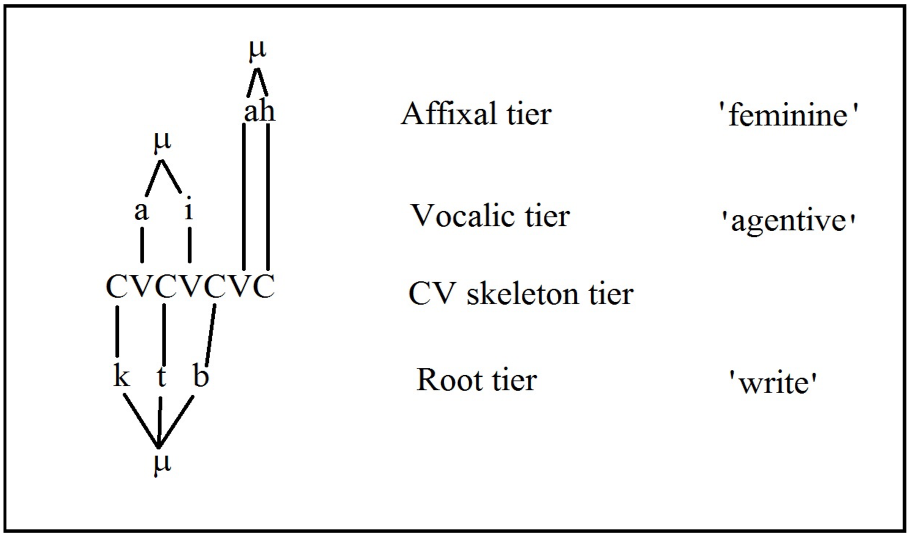

Figure 2.1: Derivation of the Arabic word *ka:tibah* ‘female writer’ in the CV-morphology hypothesis

The association of the elements on the autosegmental tiers (melodic elements) with the slots of the CV skeleton (melody-bearing elements) occurs automatically according to the three conventions in example 2.7 (McCarthy, 1981, p. 382):

(2.7) (I) “If there are several unassociated melodic elements and several unassociated melody-bearing elements, the former are associated one-to-one from left to right with the latter” (Figure 2.2, a $\rightarrow$ b).

(II) “If, after application of the first convention, there remain one unassociated melodic element and one or more unassociated melody-bearing elements, the former is associated with all of the latter” (Figure 2.2, c $\rightarrow$ d).

(III) “If all melodic elements are associated and if there are one or more unassociated melody-bearing elements, all of the latter are assigned the melody associated with the melody-bearing element on their immediate left [automatic spreading], if possible.” (Figure 2.2, e $\rightarrow$ f).

The association of the autosegmental tiers with the CV skeleton to form the surface

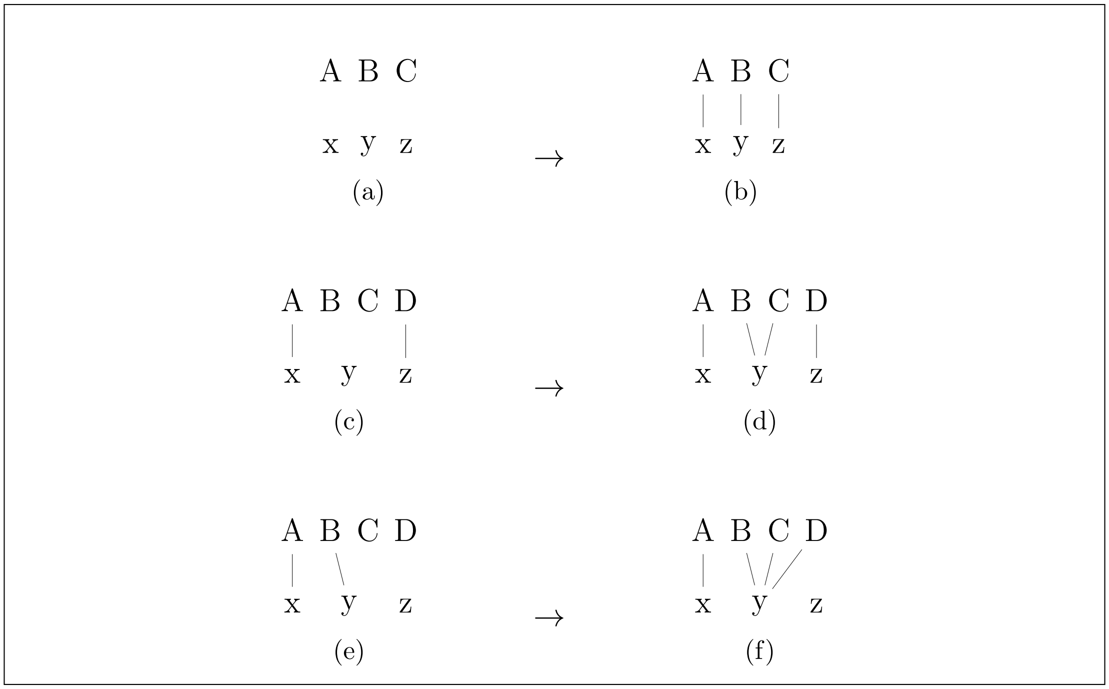

Figure 2.2: Conventions of automatic association of autosegmental tiers and CV-skeleton slots in Arabic word formation according to McCarthy (1981).

word is done via a one-to-one mapping from left to right, obeying both the principles of autosegmental phonology and any language specific phonological rules such as the OCP-place, which prevents homogeneous sounds from co-occurring within the same morpheme. This hypothesis differs from the traditional theories in two ways: first, it adds a CV skeleton as a placeholder tier that has slots for both consonants and vowels, and second, it considers the vowels as a morpheme and represents them in a separate tier. This hypothesis is challenged by the prosodic morphology hypothesis (McCarthy & Prince, 1990b).

2.3.1.2 Prosodic morphology hypothesis

Prosodic morphology is a hypothesis that describes the interactions between phonological and morphological determinants of linguistic forms and explains how prosodic structure affects the morphological shape of words, stems and morphemes (McCarthy & Prince, 1990b). While the CV morphology hypothesis refers to segments in its analyses, the prosidic morphology hypothesis (McCarthy & Prince, 1990b) employs hierarchically-built prosodic units: mora (μ), syllable (σ), foot (F) and phonological word (W). This hypothesis has four advantages over the CV morphology hypotheses according to the authors. First, it uses prosodic units, which are independently motivated in prosody which is not the case for segment in the CV skeleton concept. Second, the prosodic template offers the possibility for connections between the different aspects of Arabic, such as foot, word and minimality. Third, the prosodic morphology hypothesis has been found to be more reliable in forcing correct analyses for which the CV skeletal theory fails to account, such as some cases of the broken (irregular) plural forms. Finally, the prosodic morphology hypothesis is more restrictive and hence more predictable and learnable (McCarthy & Prince, 1990b, pp. 5–6).

In the prosodic morphology hypothesis, the units are hierarchical from top to bottom. The phonological word consists of one or more foot and the foot consists of one stressed syllable and usually an unstressed syllable. Each syllable can be light or heavy. Light syllables are monomoraic (contain one mora only) of the shape **CV**, whereas heavy syllables are either bimoraic (containing two moras) of the shape **CVV** or of the shape **CVC**. Applying this to Arabic noun morphology, McCarthy and Prince (1990b) found that an Arabic stem may contain one bimoraic syllable or a maximum of two syllables with at least one of them being heavy. For instance, the word *ka:tib* 'writer' is analyzed as a phonological word containing one foot which contains two heavy syllables (**kaa** and **tib**). This is illustrated in Figure 2.3 below. Other constraints account for gemination, reduplication and broken plural in Arabic (for detailed discussions of these constraints, see McCarthy and Prince (1990a, 1990b); and McCarthy (2006)).

Despite the differences between the hypotheses discussed above, they, as a whole, support root and pattern morphology and the concept that the Arabic lexicon uses these morphemes as its basic units. This is reflected in psycholinguistic models, where both the

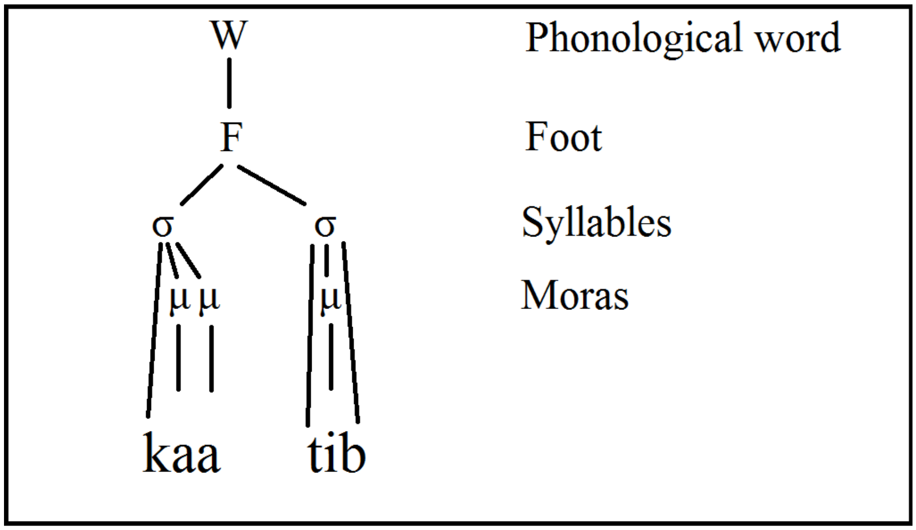

Figure 2.3: Derivation of the Arabic word *ka:tib* 'writer' in the prosodic morphology hypothesis.

Arabic root and pattern have been considered processing units that are cognitively used to access words in the mental lexicon. This view is in line with decompositional accounts of word recognition (e.g., Caramazza et al., 1988; Taft, 1981; Taft & Forster, 1975), which argue that word recognition involves a level for morphological processing at which (at least some) complex words are decomposed into their constituent morphemes. These accounts are discussed in more detail in Chapter 3. This morpheme-based theory is challenged by the stem-based theory, which claims that the Arabic stem is the basic unit in the Arabic lexicon and discards the root and pattern as an important units in Arabic word formation. Consequently, in the stem-based theory, the root and pattern are not involved in word recognition as processing units. The stem-based theory is briefly discussed in the next section.

2.3.2 Stem-Based Theory

Although the root to template is the dominant theory for Arabic word formation, some theories do not acknowledge the role of the consonantal root in the process of word formation in Arabic and by extension Semitic. Even McCarthy and Prince (1990a) consider the broken plural an exception to the root and pattern approach, and analyze it as a mapping process from singular forms to iambic templates. As a consequence, Ratcliffe (1997) argues against the root and pattern theory and espouses the stem-based theory. According to him, since the root to template morphology is only applicable on a subset of the Arabic words whereas others (such as broken plurals) are stem-based, it would be simpler and more economical to adopt the stem-based approach. He also provides some examples of Arabic nouns on which the root and pattern analysis cannot be applied. These are underived nouns of the form CVCC such as the words in example 2.8:

(2.8) (a) qird 'monkey'

(b) rumħ 'spear'

(c) kalb 'dog'

In example 2.8, each word consists of four sounds: three consonants and a vowel. If all three consonants in each word is a root morpheme, then the remaining vowel in each word should be considered another morpheme as well, which is problematic. According to Ratcliffe (1997, p. 151), this vowel cannot be considered a separate morpheme since it does not carry any independent meaning. Furthermore, the vowel in such words is unpredictable as any of the three vowels of Arabic can occur in the CVCC noun pattern. Heath (2003) uses similar examples to the ones in example 2.8 and argues that there is no reason to decompose such underived forms into roots and patterns. He argues for the imperfective verb form and the singular noun forms to be the input for verbal and nominal derivations respectively. This way, he argues, "Arabic lexical structure can be reconciled with the great majority of other languages" (p. 129).

Benmamoun (1999, 2003) supports the stem-based account of Arabic word formation. According to (Benmamoun, 1999), the imperfective verb is the form used as an input to derive other verbal and nominal forms. He argues that the imperfective is the best candidate to be the input to word formation process for two reasons: first, it is not specified syntactically for tense and aspect unlike perfective forms and hence he considers to be it the unmarked default form of verbs. Second, the vowels of imperfectives are preserved in nominal and imperative forms. Consider examples 2.9 and 2.10 from Benmamoun (1999, p. 191).

(2.9) (a) yu-ʕallim (3-teach - imperfective) 'he teaches'

(b) mu-ʕallim (NOM-teach) 'teacher'

(c) ʕallam (3ms-teach.past - perfective) 'he taught'

(2.10) (a) yu-sa:ʕid (3-assist - imperfective) 'he assists"

(b) mu-sa:ʕid (NOM-assist) 'assistant'

(c) sa:ʕad (3ms-teach.past -perfective) 'he assisted"

In the examples above, the imperfective forms and the nominal forms share the same stem vowels, but the perfective forms do not. As such, he concludes that nominals are derived from the imperfective rather than the perfective. He also provides a similar argument on the basis of imperative forms, which also share the same stem vowels with the imperfective. See example 2.11 from Benmamoun (1999, p. 192).

(2.11) (a) ta-drus (2ms-study - imperfective) 'you study'

(b) ʔu-drus (2ms-study - imperative) 'study!'

(c) daras-ta (2ms-study.past -perfective) 'he studied'

Similar arguments for the stem-based approach come from studies on Modern Hebrew word formation (e.g., Arad, 2003; Bat-El, 1994; Ussishkin, 1999). These studies suggest that word formation is an output-output process in which words are derived from other surface forms. Bat-El (1994) claims that morpheme-based theories (McCarthy, 1979, 1981) fail to explain the phenomenon of consonant cluster transfer. She noted that consonant clusters in many denominal verbs (e.g., *priklet* 'to practice law") and verbs derived from borrowed nouns (e.g., *tilgref* 'to telegraph") were preserved. If word formation was based on extracting a given root from a noun and interleaving it with a word pattern as suggested by the root-pattern theories, then a denominal word formation should extract the consonants of the noun and interleave these root consonants with an appropriate pattern (e.g., CCVCCVC or CVCCCVC) whether the consonant clusters were preserved or not. However, this was not the case for many modern Hebrew denominal verbs. For instance, the formation of a denominal verb such as *priklet* 'to practice law' should hypothetically go through root extraction from the noun ([prklt] from *praklit* 'lawyer') and then these extracted consonants interleave with an appropriate pattern (e.g., CVCCCVC; CCVCCVC). Although the expected pattern with respect to the Sonority Sequencing Generalization would be the pattern CVCCCVC and the expected output would be **pirklet*, it seems that speakers favour a form that preserve the consonant clusters of the input noun and hence used the less expected pattern CCVCCVC to get the attested output form *priklet*.

According to Bat-El (1994), this favouring of one acceptable output form over another cannot be explained by the root and pattern accounts because roots (e.g., [prklt]) do not carry any information that allows for the clusters (e.g., /pr/ and /kl/) to be preserved in output forms. This according to her, disproves the theory of root extraction on which root and pattern theories are based. Instead, Bat-El (1994) adopts the Stem Modification analysis (McCarthy & Prince, 1990a; Steriade, 1988) as an alternative framework to account for denominal verb formation in Modern Hebrew (see Bat-El (1994) for more details on this alternative account).

The Optimality Theory analysis of biliteral denominal verbs in Modern Hebrew by Ussishkin (1999) provided support to Bat-El (1994). In his analysis, he used the Correspondence Theory (MacCarthy & Prince, 1993) as his framework. According to this theory, correspondence refers to the formal mechanisms that enforce identity relations between inputs and outputs. This rule states:

> "Given two related Strings S1 and S2, correspondence is a relation R from the elements of S1 to those of S2. Elements $\alpha \in S1$ and $\beta \in S2$ are referred to as correspondents of one another when α R β" (MacCarthy & Prince, 1993, p. 262).

The analysis showed that denominal verbs in Modern Hebrew retain the base structure of the nouns from which they were derived. Thus, he argues that the derivation of Modern Hebrew denominal verbs is an output to output correspondence and that the consonantal root plays no role in Modern Hebrew denominal verb formation. He also claims that the Correspondence Theory is a superior framework for analyzing all instances of denominal verbs in Modern Hebrew. Similarly, Ussishkin (2005) claims that there are no consonantal roots in Modern Hebrew. He instead claims that there is a morphologically underived form that serves as a base of affixation for further derivations.

Arad (2003) does not completely reject the root to template word formation. She argues that Bat-El (1994)s conclusion is too strong in completely rejecting the root to template word formation in Modern Hebrew and that there are still words that are root-derived. Therefore, she suggests that words in Modern Hebrew can be formed by either approach. This claim by Arad (2003) coincides with previous argument by (McCarthy & Prince, 1990a) holding that some Arabic words are processed via their constituent morphemes, whereas other words such as the broken plural are accessed via the whole forms of their singulars.

Overall, the stem-based theory is in line with the full-listing accounts of morphological processing in the sense that it does not implement the root and pattern as input units in Semitic word formation, and hence they cannot be cognitive processing units.

2.3.3 Summary and Implications

The discussion in this chapter has provided a short overview about Arabic phonology and morphology. With regard to phonology, I have discussed the consonantal and vowel systems and introduced some of the main Arabic phonological rules. The discussion has also focused on the status of the Arabic consonantal root within two main theories of Arabic morphology: the morpheme-based theory and the stem-based theory. In this discussion, more than one proposal or hypothesis within each theory has been discussed. The present study aims, among other things, to test the two main theories. However, it does not aim to seek evidence in favour of any of the proposals and hypotheses discussed within each of the two main theories.

The controversy surrounding both the morpheme-theory and the stem-based theory has implications for lexical access and processing. These theories have informed and influenced the theories of word recognition that will be discussed in the following chapter. More specifically, the morpheme-based theory is in line with the decompositional accounts of complex word recognition (decompositional and dual) (e.g., Taft & Forster, 1975). This theory claims that morphologically complex words are decomposed into their constituent morphemes during the process of word recognition. The stem-based theory, on the other hand, is consistent with the full-listing account (e.g., Butterworth, 1983) which assumes that morphologically complex words are fully listed in the mental lexicon and that they are independent of the forms from which they are derived; hence decomposition is irrelevant to the process of word recognition. Therefore, proponents of the stem-based theory advocate single route models that deal with all words in the mental lexicon in a consistent way and view morphological complexity as a byproduct of phonological and semantic overlaps. In the following chapter, I discuss the different models of SWR and provide a review of relevant psycholinguistic research on phonological, semantic and morphological effects in SWR.

Chapter 3

Spoken Word Recognition

This chapter introduces the process of spoken word recognition and explains the different phases and mechanisms involved. It also reviews the way the current models of SWR explain and account for phonological, semantic and morphological effects. Since this dissertation is interested in a language that features a complex lexical morphology, models of SWR for morphologically complex words are also discussed. This will be followed by a review of the experimental research methods that have been used to investigate SWR in Arabic and other languages.

3.1 Introduction

Spoken word recognition (SWR) is a complex process that includes the activation of word candidates based on the acoustic properties of an input, the selection of the word that best matches these properties, and finally the recognition of the selected word (Dahan & Magnuson, 2006, p. 251). Frauenfelder and Tyler (1987) define four phases that are involved in the process of SWR, namely the initial lexical contact, activation, selection, and recognition. The initial lexical contact takes place when the listener receives the input (speech waves) and generates abstract representations that can activate the lexical representations that are stored in the mental lexicon. Abstract representations at this stage can be phonemes, syllables or spectral templates. Activation occurs when some lexical entries are activated after the initial contact. Lexical entries that match the input are activated and compete for selection. Selection occurs when one lexical entry is selected from the set of the activated lexical entries. Finally, recognition refers to the point at which the listener has recognized the word he/she heard.

Despite the complexity of this process, humans can successfully understand what is said in the numerous conversations they encounter every day. Throughout the literature, researchers have investigated the nature of SWR in many languages and theorized different models of SWR that provide different explanations for the mechanisms involved in this process. In this review, I focus on four of the most influential models and use them as a general framework for this research as they are considered the most influential models (Weber & Scharenborg, 2012) and because they are directly linked to the variables examined in this dissertation. These models are the cohort model (Marslen-Wilson & Welsh, 1978); the distributed cohort model (DCM) (Gaskell & Marslen-Wilson, 1997, 1999); the TRACE model (McClelland & Elman, 1986); and the neighbourhood activation model (NAM; Luce & Pisoni, 1998). For a more detailed review and discussion of other models, see Diependaele, Sandra, and Grainger (2005); McQueen and Cutler (1998); and Weber and Scharenborg (2012).

Despite the fact that these prominent models provide different explanations of the mechanisms involved in the process of SWR, they all agree that the recognition of a spoken word involves activation and competition. At these two levels, candidate words are activated based on their phonological and semantic features. They also agree that linguistic information is incrementally processed across phonological, semantic and contextual representations during the process of SWR. However, these models do not implement the effect of morphology in SWR as a result of independent morphological processing but consider it as a by-product effect resulting from phonological and/or semantic effects (Plaut

& Gonnerman, 2000; Zwitserlood, Bolwiender, & Drews, 2005). Therefore, another area of psycholinguistic research has been dedicated to investigating morphological processing in word recognition. This body of research investigates complex words including inflected, derived or compound words to see whether they are processed as whole words or they are first decomposed into their constituent morphemes. Based on this body of research, several models of complex word recognition have been suggested. In my review, I discuss two types of models. Some of these models do not consider the existence of an independent morphological decomposition unit in SWR and suggest that there is no need for a morphological unit to be included in the broad model of SWR. Other models argue for the existence of morphological effects in SWR, and thus the existence of morphological processing.

Research investigating SWR has used a variety of methods to test models. In this review, I focus on two behavioural methodologies: the priming paradigm and the visual world paradigm with eye tracking. Priming experiments take different forms: lexical decision tasks (LDTs), identification in noise and shadowing tasks (Dufour, 2008). In LDTs, participants are presented with two stimuli (a prime and a target) and are asked to decide whether the target is a word or a non-word. LDTs in spoken word recognition studies can be auditory-auditory with both primes and targets presented auditorily (e.g., Schluter, 2013) or cross-modal with the prime being auditory whereas the target is presented visually as printed words (e.g., Boudelaa & Marslen-Wilson, 2015). In shadowing tasks, participants are presented with a prime and then with a target. Participants are asked to ignore the prime and repeat the target. In perceptual identification in noise tasks, the auditory primes are presented without noise and then a target is presented in white noise and the participant's task is to listen to both but respond only to the target by writing it down on an answer sheet. In all types of priming tasks, priming effects occur when a prime that is phonologically and/or semantically related to the target facilitates or inhibits the recognition of the target compared to an unrelated prime. A facilitatory effect occurs when the response times to targets primed by related items are significantly shorter than the response times to targets primed by unrelated items (Dufour, 2008; Slowiaczek, McQueen, Soltano, & Lynch, 2000).

The visual word paradigm with eye tracking has also been used to investigate SWR. It is an excellent method for studying language processing for two reasons. First, it explores the interplay of language, vision, memory and attention. Second, it provides more finely grained details about the time course of lexical access (Huettig, Rommers, & Meyer, 2011). In these types of experiments, participants are instructed to listen to a spoken word and click on one of two or more pictures shown on a computer screen while the fixation location and fixation duration are measured. Results of such experiments have shown that target pictures and pictures that are phonologically, semantically or morphologically related to the spoken word receive longer fixations than other unrelated pictures.

As this research is interested in exploring the effects of phonological, semantic and root activation in SWR in Arabic, the next few sections discuss these effects in light of the current models of SWR. Previous research that has found evidence for these effects is also discussed.

3.2 Phonological, Semantic and Morphological Effects in SWR

3.2.1 Phonological Effects

All models of SWR propose that as we hear a given word, words that sound similar to the heard word become partially activated. However, the nature and mechanisms of activation are different from one model to another. For instance, activation in the cohort model (Marslen-Wilson, 1987; Marslen-Wilson & Welsh, 1978) is different from activation in other models such as the TRACE model (McClelland & Elman, 1986) and the neighbourhood activation model (NAM) (Luce & Pisoni, 1998) in that the cohort model is constrained to the set of words that start with the same onset with the possibility of backtracking to recover any misheard sounds (Marslen-Wilson, 1987). These words constitute the initial cohort that becomes available for competition and recognition. By contrast, the activation process in the TRACE and NAM are continuous, that is, they assume that every incoming speech segment can activate the set of words that contain it. Therefore, an input such as *dark* may activate words like *park*, *shark* and *mark* according to these models. Activating such words is hard to explain within the cohort model (especially the early versions) as it generates its cohort based on the onset.

The next section selectively reviews the psycholinguistic literature on the effect of phonological activation in SWR. The results of this literature are discussed in light of the current models of SWR.

3.2.1.1 Evidence for phonological effects in SWR

Several priming studies on phonological activation showed facilitatory priming effects when words were primed by fragments of words that phonologically overlapped with targets both initially (e.g., Marslen-Wilson & Zwitserlood, 1989; Radeau, Morais, & Segui, 1995; Slowiaczek et al., 1987) and finally (e.g., Andrews, 1992; Dumay et al., 2001; Pisoni & Luce, 1987; Radeau et al., 1995; Slowiaczek et al., 2000, 1987). For instance, Zwitserlood (1989) used a priming lexical decision task to investigate the importance of word onsets in SWR. She found that Dutch adults were faster at recognizing target words when they were primed by fragments of words that matched the onset of words semantically related to the targets. That is, they recognized words such as *boot* "ship" when primed by the fragment [**kapi**] which is a fragment of the word *kapitein* "captain". The priming effect can be as strong as when the word *boot* "ship" is primed by the whole word *kapitein* "captain". The author concluded that candidates that share the same onset are co-activated at a sub-lexical level. Similar results were obtained by Marslen-Wilson and Zwitserlood (1989) in English, and by results from other studies using identification tasks (Andrews, 1992; Hamburger & Slowiaczek, 1996; Pisoni & Luce, 1987; Slowiaczek & Hamburger, 1992; Slowiaczek et al., 1987). These studies provide support for the cohort model which places importance on word onset in creating the cohort of the candidate words.

However, these findings have been challenged by other studies that used the same methodologies but found inhibitory or no effect for phonological overlap (Dufour & Peereman, 2003; Monsell & Hirsh, 1998; Radeau et al., 1995). For instance, Slowiaczek and Pisoni (1986) conducted an auditory lexical decision task to investigate the priming effect of phonological similarity between primes and targets in initial position. The similarity between the prime and the target was varied to determine whether the priming effect varied as a function of the amount of similarity. Therefore, the similarity was full (*dread* - *dread*), three initial phonemes (*dress* - *dread*), two initial phonemes (*drill* - *dread*) or one initial phoneme (*dove* - *dread*). The results showed that only primes that are identical to the target showed priming effects whereas primes with one, two or three similar phonemes showed no priming effects. Priming studies using shadowing tasks have demonstrated contradictory results regarding the effect of onset in SWR. Slowiaczek and Hamburger (1992) found a facilitatory priming effect for an initial overlap of one or two segments but an inhibitory effect with three segments overlapping. By contrast, Dufour and Peereman (2003) found an inhibitory priming effect with initial overlap of 2, 3 and 4 segments.

Unlike the priming effect of initial overlap, the priming effect of final overlap in most of the studies in the literature is more straightforward. Facilitatory priming was obtained from LDT (Monsell & Hirsh, 1998; Radeau et al., 1995; Slowiaczek et al., 2000), shadowing tasks (Dumay et al., 2001; Radeau et al., 1995; Slowiaczek et al., 2000) and identification tasks (Slowiaczek et al., 1987). Dufour (2008); Goldinger, Luce, and Pisoni (1989); Radeau, Morais, and Dewier (1989); Slowiaczek and Pisoni (1986) attribute this contradiction in results for these priming experiments to the experiment type (shadowing, LDT, masked or unmasked, etc.), selection of stimuli (whether they were accurately controlled and whether they include foils and fillers), the inter-stimuli intervals (the differences of silence durations between the presentation of primes and targets), and to the strategies that participants may adopt to maximize their performance in a given task. Dufour (2008) highlights the need for more carefully designed priming experiments in order to better investigate these effects.

Visual world paradigm with eye tracking is another paradigm that has been used to investigate phonological activation in SWR (Alamri & Zamuner, 2015; Allopenna et al., 1998; Magnuson, Tanenhaus, Aslin, & Dahan, 1999; McMurray, Tanenhaus, Aslin, & Spivey, 2003; Zamuner, Moore, & Desmeules-Trudel, 2016). These studies have demonstrated that eye movements are more drawn to phonological competitors sharing the same onset or rhyme with targets compared to phonologically unrelated ones. For instance, Allopenna et al. (1998) investigated the effect of cohorts (e.g., *beetle/beaker*) and rhymes (*beaker/speaker*) in SWR in English. Their results showed high mean fixations to cohort competitors early in the time course of word recognition and a lower mean fixations to rhyme competitor in a later time window. Their results indicate the important role of both onset similarity and rhyme in SWR, providing support for the interactive models of SWR (e.g., TRACE and NAM) that assume that lexical activation is based on gradient matching with the input.

Magnuson, Dahan, Allopenna, Tanenhaus, and Aslin (1998) used the same paradigm to examine the effect of phonological activation as a function of other variables including the number and frequency of cohort and rhyme competitors. They used a lexicon of novel names that referred to novel shapes and trained their participants on this lexicon. The lexicon had a varied number of competitors per word, i.e., some words had more competitors than the others. The frequency of these words were varied during the training sessions in order for some of the words to appear more frequently than others. They used this design in an attempt to understand the development of lexical dynamics as words are learned. It also allowed the researchers to have control over the factors of neighbourhood density and word frequency. Results showed that there was onset and rhyme effect as a function of similarity between competitors and targets. With regard to frequency, cohort competitors with high frequency received higher activation than cohort competitors with low frequency. These results provided support for the interactive activation models of SWR, especially the NAM (Luce & Pisoni, 1998), which explicitly confirms the effects of neighbourhood density and neighbourhood frequency in SWR. Alamri and Zamuner (2015) conducted an eye tracking study to investigate the effect of phonological overlap (among other effects) in SWR in Arabic. In this experiment they compared fixation proportions to targets and competitors sharing the same onset (two to three initial segments). Their results showed that participants looked more to phonological competitors than to unrelated distractors. Their analysis revealed a decrease in fixations to targets early in the time course followed by an increase around 450 ms after word onset. The authors explained this observation as an early effect of the presence of phonological competitors sharing onsets with targets. As more segments unfolded and the competitors became acoustically inconsistent with the spoken word, the effect of competitor decayed and fixation to targets increased.

The review above shows that priming studies on SWR have provided various results on the phonological effect in SWR. VWP with eye tracking studies, on the other hand, have provided more finely grained details about the time course of lexical access and hence have enabled researchers to make inferences based on the position of acoustic overlap and the time at which activation occurs (Yee & Sedivy, 2006). The discussion above also shows that phonological activation can be accommodated by the current models of spoken word recognition. However, the findings on the effect of rhyme overlap can be better explained in light of the interactive activation models which argue that phonological activation occurs continuously as the incoming acoustic signals unfold which do not require the generation of cohort of candidate prior to competition.

In this dissertation, phonological activation in Arabic SWR was investigated using different manipulations of the stimuli. In Experiment 1, the effect of phonological onset (initial portions of words) is investigated, whereas in Experiment 2, phonological effect, with and without onset overlap, is investigated. The next section reviews the effect of semantic activation in SWR.

3.2.2 Semantic Effects

Despite the fact that all the models acknowledge the effect of semantics in SWR and that semantically related words are connected somehow in the mental lexicon (Goldinger, Luce, Pisoni, & Marcario, 1992; Hutchison, 2003), none of them (except the DCM; Gaskell & Marslen-Wilson, 1997, 1999) provide a specific explanation of the nature of this effect. The level at which semantic effect can occur differs from one model to another. For instance, the cohort, TRACE and NAM place semantic effects at the lexical level whereas the DCM places it at the sublexical level.

The TRACE and NAM are interactive activation models that feature bidirectional flows of information from one level to another during the process of SWR. That is, they involve both bottom-up and top-down flow of information. Therefore, semantic, syntactic and contextual features can provide feedback to the sublexical level which may increase or decrease activation of words. In these models, winning words are the ones that receive the highest activation value or reach certain activation thresholds, and hence, activation and competition are inseparable (Shoemaker, 2009). Speech recognition in DCM involves direct mapping from phonetic features onto distributed abstract representation (lexical knowledge) for both form and meaning, simultaneously allowing for parallel activation of both phonological and semantic features.

Despite the controversies on the role of semantic effects and when they may occur, there is ample evidence that as we hear a spoken word, the semantic information of that word and other words sharing the same onset is accessed. Semantic information of rhyming words is also accessed but to a lesser degree. The following section reviews the effect of semantic activation in SWR. The review is limited to the studies relevant to the current work.

3.2.2.1 Evidence for semantic effects in SWR

Semantic effects can be investigated based on meaning similarity alone (knowledge-based activation) or based on phonological overlap (form-based activation). In the former case, the focus on whether words that share some semantic and/or associative features (e.g., *cat* - *dog*, *school* - *teacher*) are linked in the semantic memory and hence hearing or reading one word activates the other. In the latter case, the focus is on the interaction between phonological and semantic activation. That is, such research investigates whether the semantic representations of phonologically activated words are also activated or not. So, when a word like *cat* is heard or read, other words that phonologically overlap with it such as *cup* are activated and the question is whether the semantic representations of the word *cup* (which was activated based on form) are activated as well (Goldinger et al., 1992; McNamara, 2005).

The priming paradigm has been used to investigate these two types of semantic activation. In studies investigating knowledge-based semantic activation, participants hear a prime (e.g., *cat*) and then hear a target (e.g., *dog*) and the interval between prime and target can vary from 50 to 500 ms or more. Participants are instructed to ignore the first word and decide whether the second one (the target) is a word or nonword. This kind of experiment investigates the effect of semantics in word recognition by virtue of words' meanings. Previous research has found that when a word is primed by a semantically related prime, the prime automatically activates its abstract semantic representation and that this activation spreads to the representations of semantically related words and facilitates the recognition of targets (Collins & Loftus, 1975; Hutchison, 2003).

In form-based semantic priming, the prime and the target are not semantically related but they share one or more phonemes word initially or finally. They are derived by the assumption that hearing a sequence of phonemes activates all the words that share some or all of the phonemes in that string and the meanings are activated. Thus, participants are presented with a prime, such as *hammock*, and are asked to make a decision on a target, such as *nail*, assuming that *hammock* activates its onset competitor, *hammer*, which in turn activates the semantically related word *nail*. The majority of research on semantic priming has been concerned with form-based design as it can provide insight about whether semantic access can occur before the spoken word is recognized.

Several priming studies (mainly cross-modal lexical decision tasks) (e.g., Marslen-Wilson & Zwitserlood, 1989; Moss, McCormick, & Tyler, 1997; Moss et al., 1997; Zwitserlood, 1989) have investigated whether the meanings of words that have initial or the final overlap with targets (competitors) are activated during SWR. In these studies, written target words are presented after different durations from the onset of auditory primes and before the uniqueness point, which is the point at which only one word matches the speech segments of the prime. The results of these studies showed that the meaning of the targets and the potential onset competitors become available early in the time course of SWR, even before the uniqueness point. These results provided evidence for parallel activation of form and meaning.

With regard to whether the meanings of words overlap word-finally with a given spoken word (rhyme competitors), there is no priming evidence for semantic activation of multiple rhyme competitors during SWR (Marslen-Wilson, Moss, & van Halen, 1996; Marslen-Wilson & Zwitserlood, 1989; Moss et al., 1997). For instance, Marslen-Wilson and Zwitserlood (1989) found that the meanings of rhyme competitors which overlapped completely except for the initial phoneme are not activated. For example, the prime *money* did not activate the target *bee* which is semantically related to the rhyme competitor *honey*.

Eye-tracking has also been used to investigate semantic activation in SWR and studies have found that semantic information about potential competitors is activated during the early stages of the process (Apfelbaum et al., 2011; Huettig & Altmann, 2005; Mirman & Magnuson, 2009; Yee & Sedivy, 2006). This methodology has been found to be "a powerful tool that can detect semantic similarity effects" (Mirman & Magnuson, 2009, p. 1036). Huettig and Altmann (2005) conducted an eye tracking study to investigate semantic activation as a function of conceptual similarity between targets and competitors. In this experiment, participants were shown a display of four pictures and there were three conditions. In the target condition, a picture of the target (e.g., *piano*) appeared with three unrelated distractors. In the competitor condition, a picture of a semantic competitor (e.g., *trumpet*) was displayed with three unrelated pictures. Finally, in the target and competitor condition, the target and competitors were presented with two unrelated pictures. In all conditions, a sentence carrying the target word (e.g., *piano*) was played 1 second after the visual. Participants were instructed to listen to the sentences carefully and look anywhere they wanted on the screen. Results showed that more visual attention was directed towards targets (e.g., *piano*) in the target condition and towards competitors (e.g., *trumpet*) in the competitor condition. In the target and competitor condition, more visual attention was directed towards targets than to the competitors and distractors but more towards competitors compared to unrelated distractors. Similar results were obtained by Mirman and Magnuson (2009) who found higher proportions of fixation drawn to semantic competitors (e.g., *blackbird*) that are conceptually related to targets (e.g., *eagle*) than to semantically unrelated competitor (e.g., *trumpet*). They also found that semantically related competitors received high fixation proportions even when they had distant association with the target (e.g., *eagle/tiger*). These results provided evidence for early activation of conceptual semantic representations in SWR.

Along the same line, Yee and Sedivy (2006) conducted two eye tracking experiments to investigate semantic activation in SWR in English. The first experiment was intended to explore the time at which semantic information is available during the process of word recognition. In this experiment, four images appeared on the screen (e.g., *lock, key, deer* and *apple*) and the spoken word was played (e.g., *lock*). Results showed more visual attention directed towards the images of the target (*lock*) and the semantically related word (*key*). In Experiment 2, the same design and procedure were used but the target words were replaced by words that were cohort competitors of these words. For instance, the word *lock* was replaced by *log*. So, participants saw four images of *log, key, deer* and *apple* and heard the spoken word *log*. Note that the word *key* was semantically related to the word *lock*, which was not one of the four images displayed. Results of this experiment also showed that there was more visual attention directed towards the target image *log* and to image of the distractor (e.g., *key*) that is semantically related to the not-pictured onset competitor of the target (*lock*). These results suggest that not only the semantic information related to a spoken word were available during the process of recognition but also the semantic information of the spoken word's onset competitor.

Apfelbaum et al. (2011) conducted an eye-tacking study to investigate whether semantic access occurs in parallel with phonological activation and hence can be affected by the amount of phonological activation or whether access is modular (i.e., whether access to semantics only occurs after phonological access is complete). They compared semantic activation in two groups of words that differed as a function of phonological neighbourhood density (low vs. high). The assumption was that if semantic processing is modular and always happens after phonological processing is complete regardless of the amount of phonological competition, then semantic priming should not differ between words with high neighbourhood density (HD) and words with low neighbourhood density (LD). By contrast, if semantic processing occurs in parallel with phonological processing, then the amount of phonological overlap should affect semantic access. The results of their study indicated that semantic priming was present regardless of whether the targets were HD or LD, however, there was greater magnitude of semantic priming for LD words than for HD words. Words that were semantically related to LD targets were fixated more than words that were semantically related to HD targets. For example, the word *tunnel* which is semantically related to the LD target *bridge* was fixated more than the word *honey* which is semantically related to the HD target *bee*. With regard to the timing of semantic access, their results revealed that semantic processing is delayed when phonological competition is high. These results confirm that semantic activation begins before the word-form computations are completed and hence provide further support for the interactive models. They also provide support for the view that phonological and semantic processing occurs in parallel, with semantic activation being affected by the amount of phonological competition.

The research discussed above provides evidence for the existence of semantic effects in spoken word recognition. These results (especially the fine details obtained from the eye tracking paradigm) provide support for the connectionist models such as TRACE and NAM, which assume that semantic information from the lexical level can interact with phonological information at the sublexical level. They also provide support to the DCM, which explicitly argues for a parallel phonological and semantic activation. It also suggests that semantic activation is mediated by the number of candidate words. In this dissertation, semantic effects are investigated in many ways. The effect of semantic association among words is investigated in both Experiment 1 and 2. However, in Experiment 2 the effect of semantics in modulating morphological processing is explored by comparing the effect of morphological activation as a function of semantic transparency among words. The next section discusses research looking at the effect of morphology on SWR.

3.2.3 Morphological Effects

As mentioned earlier in this chapter, the morphological effects in SWR are not captured by the current models of SWR discussed to this point. The priming effect obtained for morphologically related words is explained as a result of recurrence of certain auditory clusters (McClelland & Elman, 1986). As clusters are repeatedly mapped to certain meanings, the cognitive system captures that regular mapping and generates a pattern for combining words involving these clusters of sounds (Plaut & Gonnerman, 2000). Thus, morphological complexity is not implemented in these models as a processing unit in SWR and thus simple and complex words are treated in the same way. In order to test this hypothesis, complex word recognition has been investigated in a variety of languages to explore the influence of word-internal structures for word recognition and several models have been suggested specifically to account for complex word recognition. These models can be classified into two categories: non-decompositional models (e.g., Taft, 1981; Taft & Forster, 1975) and decompositional models (e.g., Baayen et al., 1997; Butterworth, 1983; Caramazza et al., 1988; Manelis & Tharp, 1977). These models are briefly discussed in the following section (for more a detailed review, see Diependaele et al., 2005; McQueen & Cutler, 1998).

3.2.4 Non-decompositional models

As described earlier, the primary models of SWR (Cohort, DCM, NAM and TRACE) do not employ the morpheme as a processing unit and treat complex words in the same way as simple words. Therefore, these models are considered non-decompositional models. Several studies on complex word recognition provided evidence suggesting that there is no need for fitting a morphological-processing level to these models (Butterworth, 1983; Gonnerman, Seidenberg, & Andersen, 2007; Henderson, Wallis, & Knight, 1984; Manelis & Tharp, 1977; Seidenberg & Gonnerman, 2000). Based on data from these studies, many non-decompositional models (also called full-listing models) have been proposed. What all these models have in common is that they take a continuous, non-decompositional approach to word processing that holds that words in the mental lexicon are stored and processed as whole words with no effect of morphology in processing. However, the models are dissimilar in terms of their exclusion of decomposition in lexical processing. Manelis and Tharp (1977) confirm that words are listed separately regardless of morphological complexity. They came to this conclusion based on data obtained from a lexical decision task in which they compared suffixed and pseudo-suffixed words. Their results demonstrated that there is no difference between the two groups. Henderson et al. (1984), by contrast, do not completely discard decomposition. Rather, they argue that it occurs at a post-lexical level as they found no evidence for the existence of decomposition at least in the prelexical stages of word recognition.

Other proposals have attempted to provide an explanation of the priming effect found in many studies (e.g., Frost et al., 1997; Plaut & Gonnerman, 2000; Taft, 1981; Taft & Forster, 1975). For instance, Gonnerman et al. (2007); Seidenberg and Gonnerman (2000) explain the graded morphological effects they obtained in their studies in terms of connectionist models that use distributed representation rather than abstract morphemic units. Priming in morphologically related words is a reflection of graded phonological and semantic overlap. However, this conclusion is challenged by data obtained from visual masked priming, which is known for its insensitivity to semantic effects. These studies have shown that words that are morphologically related facilitate response to their stems. For example, *apartment* facilitates the recognition of *apart*. This is not the case when the words are orthographically but not morphologically related. For example, *electrode* does not facilitate recognition of *elect* (Fiorentino & Poeppel, 2007). These results suggest the existence of morphological decomposition in lexical processing and that morphological decomposition is independent from the semantic effect as the masked priming paradigm is known for its insensitivity to the semantic effects. The next section reviews the different decompositional models of SWR.

3.2.4.1 Decompositional models

Decompositional models can be classified into two categories: obligatory decomposition models (also referred to as full-parsing models; e.g., Taft, 1981; Taft & Forster, 1975) and dual-route models (e.g., Baayen et al., 1997; Caramazza et al., 1988; Giraudo & Grainger, 2000; Schreuder & Baayen, 1997). Obligatory decomposition models hold that the mental lexicon is morphologically structured and hence complex words are obligatorily decomposed (parsed) into their morphemic units. According to the obligatory decomposition models, lexical entries are morphemes rather than whole words and the mental lexicon is mainly organized based on the morphological structures of words. Dual-route models suggest that words in the mental lexicon can be decomposed into their constituent morphemes or processed as whole words. These two groups of models are discussed below.

3.2.4.1.1 Obligatory decompositional models.

The first obligatory decomposition model was proposed by Taft and Forster (1975) based on data from lexical decision tasks within the visual modality that investigated morphological processing in affixed words. The results of this study showed that participants took longer time to reject pseudo-complex words with real stems (e.g., *de-juvenate*) and pseudo-complex words with real prefixes and non-existent stems (e.g., *de-pertoire*). The authors claimed that nonwords of this type (*de-juvenate*) took longer because they were decomposed and the stem (*juvenate*) was found to be a real stem that exists in the mental lexicon. In the case of pseudo-complex words with real prefixes and non-existent stems (e.g., *de-pertoire*), the decomposition revealed a stem that did not exist in the lexicon, and hence it was rejected faster. They argued for an affix-stripping process in which affixes of a complex word are stripped at an early stage of lexical processing. The result of this stripping is identifying one or more affix and a stem. This stem is taken to the central system to be processed.

Similar results were obtained from a series of auditory and visual lexical decision tasks by Taft (1986) who compared combinations of real and non-existing stems (e.g., *joice* vs. *jouse*) and prefixes (e.g., **de** vs. **te**). Manipulating these stems and prefixes resulted in quadruplets that were used in the experiments (e.g., *dejoice, tejoice, dejouse,* and *tejouse*). His results showed that rejecting *dejoice* took longer than *dejouse* because *dejoice* contained a real stem that was identified after stripping off the prefix. He also found that *tejoice* and *tejouse* were rejected faster than *dejoice* and *dejouse*. This was attributed to the fact that *tejoice* and *tejouse* did not contain real prefixes and hence affix stripping did not occur and the stem was not identified, and hence the nonwords were rejected immediately (Taft, 1986). These results provided support for the affix stripping hypothesis (Taft, 1981, 1986; Taft & Forster, 1975).

However, a weaker version of this hypothesis was adopted based on results obtained from a later study by Taft (1988), which compared prefixed and non-prefixed words (e.g., *purity* vs. *impurity*) and nonwords (e.g., *enrapsify* vs. *rapsify*) in an auditory lexical decision task. His results demonstrated that prefixed items were processed faster than non-prefixed items in both words and non-words. These results caused the author to make some changes to the affix stripping view. In this new version, he claims that both stems and affixes can be access codes in the process of word recognition. These findings also provided evidence for the cohort model (Marslen-Wilson & Tyler, 1980), which confirms that recognition can be predicted by the uniqueness point. However, marrying this decompositional model by Taft (1988) and the cohort model (Marslen-Wilson & Tyler, 1980) is complicated by two problems. First, the effect of morphology as a function of semantic transparency (Marslen-Wilson, Tyler, Waksler, & Older, 1994) cannot be explained by this model. Second, the existence of affix stripping and recombining requires the existence of a store for affixes which was thought to be unlikely (Taft, 1994). To solve these two problems, Taft (1994) called for an alternative decompositional model that can be fitted in an interactive activation model such as TRACE (McClelland, 1987; McClelland & Elman, 1986; McClelland & Rumelhart, 1981). In such a model, he argues, "there is no need for pre-lexical prefix stripping, so there need not be any specific store of prefixes. Prefixes are nonetheless treated separately from their stems, by virtue of the fact that they constitute independent activation units" (Taft, 1994, p. 279). Therefore, Taft and Kougious (2004) proposes an obligatory decomposition account of complex word recognition that can be fit to an interactive activation model of word recognition. According to this, all words are obligatorily decomposed into their constituent morphemes at an early stage of processing. When morphemes are decomposed, their semantic representation and other representations such as base frequency (i.e., the cumulative frequencies of morphologically related forms) become available. At a subsequent combinatory stage, these morphemes are combined and other effects such as surface frequency emerge (Taft & Kougious, 2004, p. 761).

3.2.4.1.2 Dual-route models

Unlike obligatory decomposition models, dual-route models posit that morphologically complex words can be processed prelexically either via a prelexical full parsing route, which decomposes complex words into their constituent morphemes, or via a direct full listing route, which processes words as wholes. However, these models differ in describing how these two routes interact during the process of recognition. This general assumption is manifested in different hypotheses such as the morphological race model (MRM) (e.g., Baayen et al., 1997; Schreuder & Baayen, 1997), the augmented addressed morphology model (AAM) (e.g., Caramazza et al., 1988) and the supralexical model (e.g., Giraudo & Grainger, 2000). These hypotheses differ their description of the way the full-parsing and full listing are ordered in the system. The MRM and AAM argue that the full-listing and the full-parsing routes are automatically deployed prelexically in a parallel fashion. A difference between these models and the full-parsing models is that decomposition is not obligatory for processing all complex words, but rather it depends on the words' frequency, regularity and semantic transparency, among other factors (Diependaele et al., 2005; Fiorentino & Poeppel, 2007).

The supralexical model (e.g., Giraudo & Grainger, 2000), on the other hand, specifies the sublexical level for the full-listing route and places the full-parsing route at a higher stage (supralexical, which is higher than the sublexical and lower than the lexical levels). The model holds that processing starts automatically with the full-listing route accessing whole-word representations (sublexically) early in the time course of processing. Full-parsing, by contrast, is only utilized when needed to access morphological constituents and provide feedback to the sublexical level to activate words that are morphologically related. This happens only under certain circumstances, such as when the relation between whole words and constituents is semantically transparent (Diependaele et al., 2005; Giraudo & Grainger, 2000).

It is important to note that the models of complex word recognition discussed above have been mainly developed based on data obtained in Indo-European languages, which only constitute a subset of the languages of the world, and hence might not accommodate all the lexical properties found in other languages. Note that content words in Indo-European languages can be morphologically simple (words consisting of one morpheme only, such as *dog*) or complex (words consisting of more than one morpheme, such as *dogs*). This differs from Semitic languages such as Arabic, which have a non-linear morphological system in which a word is constructed non-linearly by combining a consonantal root that conveys the general thematic meaning (e.g., **ktb** 'writing') and a pattern that conveys morpho-syntactic information (e.g., the past tense pattern: **CaCaC**) producing the word (**katab** 'wrote'). This typologically unusual non-concatenative morphology of Semitic languages provides a unique test-case for the models of SWR (Boudelaa & Marslen-Wilson, 2000; Ussishkin et al., 2015). The next section discusses three decompositional models of word recognition in Semitic languages.

3.2.4.2 Decompositional models for Semitic languages

As explained in Chapter 2, Arabic (and other Semitic languages by extension) have been viewed as having a root-and-pattern morphology by the majority of old Arab grammarians such as Sibawaih (7th century) as well as the majority of western linguists (e.g., Holes, 2004; McCarthy, 1981). This view has been challenged by another line of theories referred to as the word-based theories which argue against the Semitic consonantal root. The alternative view argues that the relationships among Arabic words are mainly phonological and/or semantic rather than morphological (e.g., Benmamoun, 1999; Ratcliffe, 1997). McCarthy and Prince (1990a) also proposed that some Arabic words are processed via their bound morphemes while others are processed through word stems. Each of these theories, in fact, is supported by one or more of the models of complex word recognition discussed above. The morpheme-based theories are in line with the full parsing model (e.g., Taft, 1981; Taft & Forster, 1975), the word-based theories cohere to the full listing model (e.g., Butterworth, 1983; Manelis & Tharp, 1977) and finally the proposal by McCarthy and Prince (1990a) is supported by the dual-route models (e.g., Baayen et al., 1997; Baayen & Schreuder, 1999; Caramazza et al., 1988).

All together, few studies in Hebrew (e.g., Bat-El, 2003; Berent, Vaknin, & Marcus, 2007; Ussishkin, 1999, 2005, 2006) and one study only in Arabic (Abu-Rabia & Awwad, 2004) have provided support for the stem-based theory of Semitic languages and the non-decompositional models of complex word recognition. Rather, the majority of research on lexical processing in Semitic languages supports morpheme-based theories of Semitic morphology(McCarthy, 1981; McCarthy & Prince, 1990a, 1990b), which are in line with decompositional and dual-route models of complex word recognition.

Studies investigating morphological effects in SWR in Arabic (Boudelaa & Marslen-Wilson, 2000, 2015; Mimouni, Kehayia, & Jarema, 1998) have found facilitatory priming effects for both the root and pattern. Consequently, the authors of these studies argued for a decompositional account for SWR in which words are decomposed to their morphemic units (roots and patterns) and claimed that these units can be considered as distinct units involved in the process of SWR. These results are consistent with findings from Hebrew (e.g., Deutsch et al., 1998; Frost et al., 2000, 1997) and Maltese (e.g., Twist, 2006; Ussishkin et al., 2015). These results are supported by similar findings from a large number of studies on Arabic visual word recognition (e.g., Boudelaa & Marslen-Wilson, 2001, 2004, 2005, 2011; Mahfoudhi, 2005; Qasem, 2010).

Taken together, these studies provide evidence for the morpheme-based theories of

Semitic morphology (McCarthy, 1981; McCarthy & Prince, 1990b) and the models of word recognition that involve decomposing words into their morphemic units. These include both the full-parsing and dual-route models. In the next section, a few decompositional models that have been developed specifically to account for complex word recognition in Semitic languages are discussed (Boudelaa, 2014; Deutsch et al., 1998; Frost et al., 1997).

3.2.4.2.1 Obligatory morphological decomposition model for Hebrew

The obligatory morphological decomposition model (Frost et al., 1997) is a dual-route model for visual word recognition in Hebrew. This model consists of a word level and a root-morpheme level. Lexical units (words) are stored at the word level. At the root-morpheme level, words are obligatorily decomposed by a morphological decomposition unit. The two routes function in parallel in a non-competitive fashion. Therefore, words are processed (retrieved) as whole using the whole-word route and are decomposed into their constituent morphemes using the decompositional route. As a result of this obligatory decomposition of words, morphologically-related words are activated (see Figure 3.1). For example, when a word like *tizmoret* 'orchestra' is read, it undergoes an obligatory decomposition and thus the root **[zmr]** is identified and all words having the same root (e.g., *zamer* 'song' and *zameret* 'female singer') are activated.

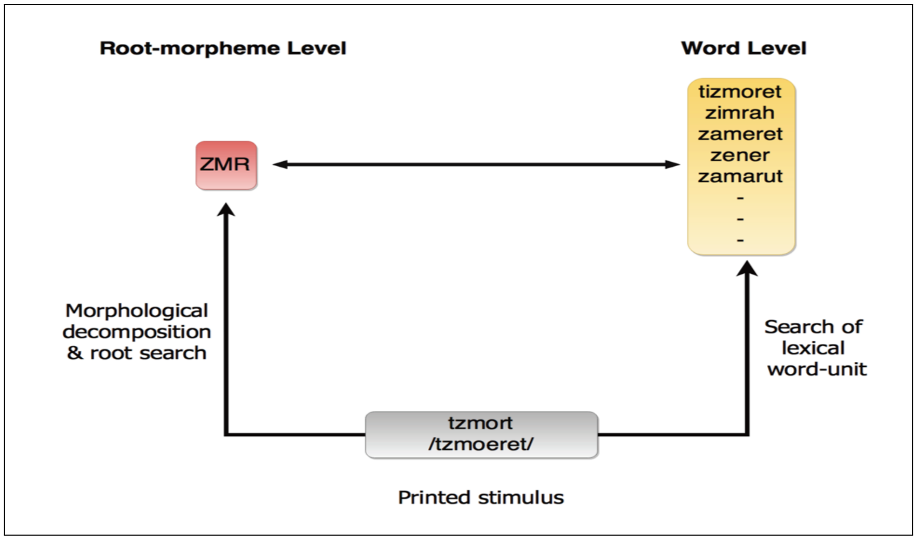

Figure 3.1: The obligatory morphological decomposition model for Hebrew nominal system (Frost et al., 1997).

Another feature of this model is that the root-morpheme level only encodes orthographic representations (phonological by extension to SWR) but not the semantic representations of the root. This feature enables the model to account for the priming effect of words that are root related but their semantic relatedness is opaque (Boudelaa, 2014). However, the model is not clear about the word pattern as a morpheme and does not explain whether its semantic information is coded or not. In addition, the model is not clear about how the two routes function in parallel (Boudelaa, 2014). This model is limited to the nominal system of Hebrew as it was based on results of priming experiments on nouns. Therefore, an extended version of this model was proposed by Deutsch et al. (1998) to capture word recognition in both the nominal and the verbal systems of Hebrew.

This extended version (named the extended obligatory morphological decomposition model) is also a dual-route model with the same levels (i.e., lexical level and sublexical level). Similar to the previous version, words are retrieved as whole using the whole-word route and are decomposed into their constituent morphemes using the decompositional route. The decompositional route involves a decomposition unit that decomposes words into their roots and word pattern. However, the nominal and verbal systems of Hebrew are treated differently in this extended model. The decompositional unit at the sublexical unit extracts both roots and word patterns of verbs. However, for nouns, the root is the only access gate as the decompositional unit is not sensitive to nominal patterns (see Figure 3.2). The nominal word patterns are only processed via the whole-word route in the context of whole words (Deutsch et al., 1998). The verbal patterns are extracted and identified at the sublexical level in this model because they consist of seven patterns only which is considered a very small number compared to more than 100 nominal patterns. This makes the verbal patterns more frequent and semantically more salient compared to nominal patterns. However, this version, like the old version, does not explain the nature of interaction between the two routes and whether each route produces an output, or whether they race and only the faster route continues to produce an output (Boudelaa, 2014; Qasem, 2010).

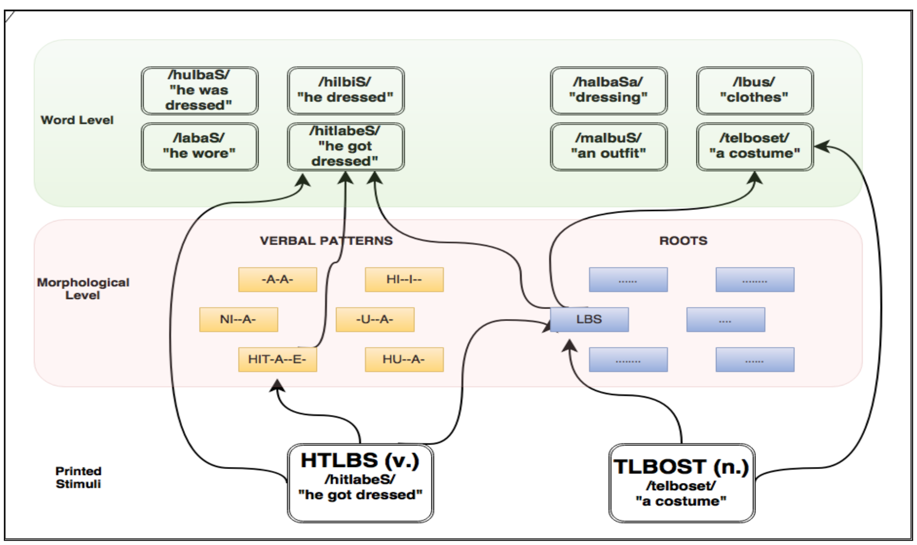

Figure 3.2: The obligatory morphological decomposition model for Hebrew verbal (v.) and nominal (n.) systems (Deutsch et al., 1998).

3.2.4.2.2 Obligatory morphological decomposition model for Arabic

Boudelaa (2014) proposes a connectionist model for Arabic word recognition similar to the obligatory model proposed by Taft and Kougious (2004). This model can be fit to an interactive activation network with localist representations corresponding to roots and word patterns. Arabic words with identifiable morphological structure are processed by an obligatory morphological decomposition unit that extracts these morphemes from the acoustic or the orthographic inputs and then accesses their phonological, semantic, morpho-syntactic and functional information. Words are decomposed regardless of their semantic transparency. However, opaque forms are mapped into a post-access recombination stage at which their interpretations are established (see Figure 3.3). This feature accounts for the fact that words sharing the same root produce a comparable amount of priming whether the semantic relatedness between primes and targets is transparent (e.g., *kitab* 'book' / *ka:tib* 'writer') or opaque (e.g., *kitab* 'book' / *kati:bah* 'squadron'). According to this model, the first prime-target pair *kitab/ka:tib* is decomposed and its meaning is established at an early stage, whereas the second pair *kitab/kati:bah* is sent to the recombination stage to receive its interpretation as a whole word. So, although this model employs obligatory decomposition, it does not neglect whole-word processing. However, Boudelaa (2014) claims that it occurs at a later stage after the early stage fails to assign the correct interpretation. The author claims that other variables such as frequency can be accounted for within this model. Root and word pattern frequency effects are expected to occur at the decomposition stage, while surface frequency effects are predicted to occur later at the recombination stage.

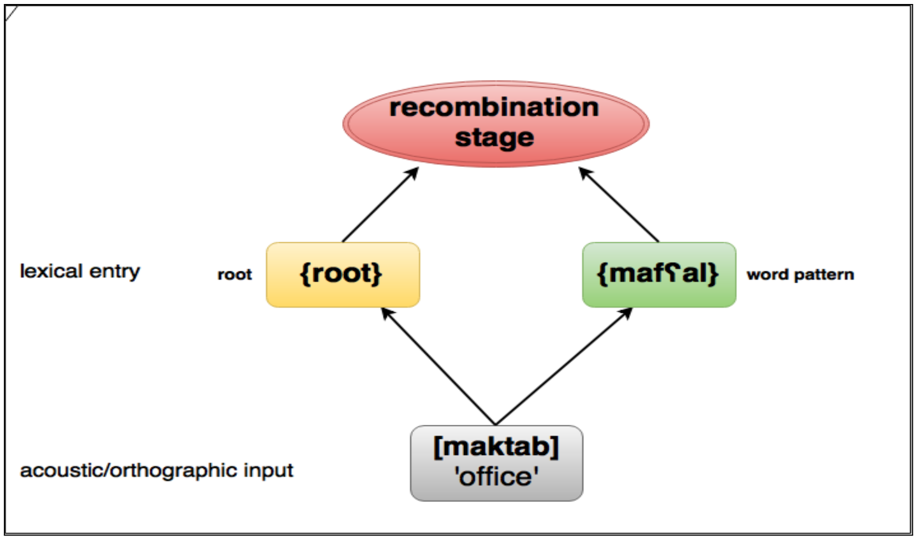

Figure 3.3: The obligatory morphological decomposition model for Arabic (Boudelaa, 2014).

The models of complex word recognition in Semitic reflect the consensus among the majority of researchers on the need for a model of word recognition in Semitic languages that involves a morphological processing level at which words are decomposed into their constituent morphemes. This issue is central to the present work and hence the experiments were designed to test the decompositional against the non-decompositional models of SWR without differentiating between the various manifestations within each set of models. Previous priming studies investigating spoken word recognition in Arabic have used similar designs and have obtained data supporting the decompositional models of word recognition (e.g., (Boudelaa & Marslen-Wilson, 2000, 2015; Ussishkin et al., 2015). The current work aims to replicate and extend their findings using a different method. The reminder of this section is dedicated to reviewing these studies in more detail.

3.3 Psycholinguistic evidence for morphological decomposition in Arabic SWR

The only known studies that have directly investigated phonological, morphological (root and pattern) and semantic activation in Arabic SWR are Boudelaa and Marslen-Wilson (2000, 2015); Schluter (2013) and Ussishkin et al. (2015). Because these studies are centrally related to the research of this dissertation, these studies will be described in detail. In all these studies, the effects of the root and pattern were investigated.

To begin, Boudelaa and Marslen-Wilson (2000) used two cross-modal tasks to investigate the status of the Arabic root and word pattern as lexical processing units. In Experiment 1, 24 target words (all nouns) were paired with 96 primes to create four different conditions. In condition 1, the primes and the targets shared the phonological form (F)(consonants and vowels of the word pattern) and the syntactic meaning of the word pattern (M; perfective, active, profession noun, etc.). This condition was labeled (+WP +F +M). In condition 2, the primes and targets shared the phonological form (F) of the word pattern but NOT the syntactic meaning (+WP +F -M). In condition 3, the primes and targets shared two consonants but did not belong to the same word pattern (+phonology). Finally, there was a baseline condition (unrelated) in which the primes and targets were unrelated (see Table 3.1).

Condition	Prime	Target
+WP+F+M	xudu:ʕun 'submission'	ħuduϑun 'entering'
+WP+F−S	suʒu:nun 'conference'	ħuduϑun 'entering'
+Phonology	ʔittiħa:dun 'outlet'	ħuduϑun 'entering'
Unrelated	qahwatun 'coffee'	ħuduϑun 'entering'

Table 3.1: Sample primes and targets for Experiment 1 in Boudelaa and Marslen-Wilson (2000).

Reaction times (RTs) in the first three conditions was compared to that of the baseline (Unrelated) condition. There was a significant priming effect for condition 1 (+WP +F

+M) compared to the baseline condition. No significant effect was found for condition 2 (+WP +F -M) compared to the baseline; however, a non-significant tendency for inhibition was found. With regard to condition 3 (+Phonology), which is the condition in which there was phonological overlap, but the shared segments were not part of the phonological structure of the pattern, there was a significant inhibitory priming effect. This inhibitory effect was attributed to some sub-lexical competition.

The goal of the second experiment carried out by Boudelaa and Marslen-Wilson (2000) was to investigate the effect of the consonantal root as a function of semantic transparency. If priming occurred even in the absence of semantic relatedness, then the effect of the root could be attributed to morphological level of processing separate from that of meaning. In this experiment, 32 target words and 128 primes were used to create four test conditions. In condition 1, the target and the prime shared the same root and had a transparent semantic relationship (+R +S). In condition 2, the target and the prime shared the same root but had an opaque semantic relationship (+R −S). In condition 3, the target and the prime did not belong to the same root but were semantically related (−R +S; see Table 3.2).

Condition	Prime	Target
+R+S	ʔidxa:lun ‘insertion’	duxu:lun ‘entering’
+R−S	muda:xalatun ‘conference’	duxu:lun ‘entering’
−R+S	manfaðun ‘outlet’	duxu:lun ‘entering’
−R−S	qahwatun ‘coffee’	duxu:lun ‘entering’

Table 3.2: Sample primes and targets for Experiment 2 in Boudelaa and Marslen-Wilson (2000).

Their results showed a facilitatory priming effect in all critical conditions; however, a significant difference was also found between the two root conditions (i.e., +R +S and +R −S) on the one hand and the conditions that have semantic overlap with or without root sharing (i.e., +R +S and −R +S) on the other. This difference suggests that words and primes that share same consonantal root prime each other irrespective of the nature of the semantic relation between them. The results of these two experiments together provided evidence for the consonantal root and word pattern as distinct lexical units involved in lexical access and demonstrated that the language processor is sensitive to these abstract morphemes.

Boudelaa and Marslen-Wilson (2015) extended their own work in the study reported above (Boudelaa & Marslen-Wilson, 2000) and another previous study Boudelaa and Marslen-Wilson (2005), which was conducted to investigate the effect of the Arabic root in visual word recognition using lexical decision tasks with masked priming. In their 2015 study, they used cross-modal priming tasks which featured auditory primes and printed visually presented targets. They conducted 5 experiments, the first two were concerned with the effect of word pattern. These two experiments were identical to Experiment 1 in (Boudelaa & Marslen-Wilson, 2000) in their design and procedure. However, Experiment 1 investigated the nominal system while Experiment 2 investigated the verbal system. In these experiments, they found significant priming effects of word pattern in both systems even when the word patterns shared by prime-target pairs differed in the core morpho-syntactic function.

Experiment 3 investigated the effect of the root as a function of semantic transparency (targets with transparent versus opaque semantic associations with primes). There were 24 deverbal nouns (nouns derived from roots) and 96 primes that were used to create four conditions (Table 3.3). First, +R+S consisted of prime/target pairs that belonged to the same root and had strong semantic associations (e.g. *mumtiʕun* 'enjoyable'/ *mutʕatun* 'pleasure'). Second, +R−S consisted of prime/target pairs that belonged to the same root but had opaque semantic associations (e.g. *mataʕun* 'commodity'/ *mutʕatun* 'pleasure'). Third, −R+S were words that did not belong to the same root but were semantically related (e.g. *laððatun* 'enjoyment'/ *mutʕatun* 'pleasure'). Finally, the unrelated condition included pairs that did not share root or semantic relations (e.g. *xara:ʒun* 'tax' / *mutʕatun* 'pleasure').

RT results of this experiment showed strong priming effects of both root conditions

Condition	Prime	Target
+R+S	mumtiʕun 'enjoyable'	mutʕatun 'pleasure'
+R−S	mataʕun 'commodity'	mutʕatun 'pleasure'
−R+S	laððatun 'enjoyment'	mutʕatun 'pleasure'
−R−S	xara:ʒun 'tax'	mutʕatun 'pleasure'

Table 3.3: Sample primes and targets for Experiment 3 in Boudelaa and Marslen-Wilson (2015)

.

(+R+S and +R−S)compared to the unrelated condition. The effects were stronger than the effect of their semantic control (−R+S), which was not significantly different from the unrelated condition. The root-related conditions did not differ as a function of semantic transparency. The authors concluded that their results replicated and confirmed their previous results in Boudelaa and Marslen-Wilson (2005) and claimed that the Arabic consonantal root is a morphological processing unit separable from the semantic and phonological units involved in the process of word recognition.

In Experiment 4, similar conditions were used; however, the primes were nouns whereas the targets were verbs. The goal of this experiment was to determine whether priming effect could be found between words sharing the same root even when they belong to different syntactic categories. Their results also found robust priming effect of the root.

Combined, the results of these experiments provided support for the root and word pattern as abstract cognitive entities that function independently from semantic and phonological factors. The facilitatory effects found for the root-related conditions (+R+S and +R−S) can explained as a result of early activation at a decompositional stage of lexical access. The inhibitory effects in the conditions that had phonologically but not morphologically related words compared to the facilitatory effect in the condition that had morphologically related words was taken as evidence that the effect of the root cannot be a result of mere phonological overlap. Their results also provided further support for decompositional models of morphological processing.

Schluter (2013) conducted over a dozen experiments to investigate the effect of the root in Moroccan Arabic. While he tested different types of root (canonical tri-consonantal roots, strong roots, weak roots, hollow roots, and lame roots), only Experiments 2, 3a and 3b are discussed here as they focussed on the canonical tri-consonantal root investigated in the current dissertation. In Experiment 2 was an auditory decision lexical decision task that was conducted to explore the extent to which the meaning of a word interacts with the word's morphology. In other words, the experiment tested whether root effect were similar to semantic effects. Stimuli were Moroccan Arabic verbs. There were 54 real word primes that were paired with real word targets and 54 non-words that were used as fillers. The stimuli appeared in four counterbalanced conditions. In the identify condition, words were identical to targets. In the control condition, words were phonologically, semantically and morphologically unrelated to targets. In the semantic condition, words were synonyms of targets. Finally, in the root condition, words were morphological relatives to targets related via roots (see Table 3.4 below). Half of the words in the root condition featured close (transparent) semantic relationships with targets whereas the other half had distant (opaque) with targets.

Condition	Prime	Target
Identity	hbətˤ 'come down'	hbətˤ
Control	fləq 'unsew'	hbətˤ
Semantic	nzəl 'go down'	hbətˤ
Root	həbbətˤ 'bring down'	hbətˤ

Table 3.4: Sample primes and targets for Experiment 2 in Schluter (2013)

Participants heard an audible spoken prime and an audible spoken target with a 150ms interstimulus interval. Participants were asked to respond to the second word they heard (targets). Results of RTs from both word onset and word offset showed no significant difference between the semantic and control conditions. RTs in the root condition and identity condition significantly differed from those of the control condition but not from each other. These results indicated that semantics play little or no role in lexical access to Moroccan Arabic verbs whereas morphology (root) was found a significant contributor to lexical access. Comparing the two types of root related words in the root condition (close vs. distant), results showed no significant difference between the two types indicating that semantic transparency play little or no role in root priming.

Experiment 3a and 3b examined the extent to which phonological form interacts with the morphology of the word. The same stimuli were used in the two experiments, however, in Experiment 3b, the recordings used as primes and targets were manipulated by compressing their duration to 220 or 240ms so that they are inaudible. The stimuli were 48 moroccan Arabic verbs that were selected to appear in four counterbalanced conditions. The conditions were identical to those of Experiment 2 except for that the semantic condition was replaced by a phonological condition in which words shared the first and third consonants as the targets, but differed in the second consonants (see Table 3.5).

Condition	Prime	Target
Identity	xtər 'become thick (of liquids)'	xtər
Control	mrəʒ 'spoil (of fruits and vegetables)'	xtər
Phonology	xmər 'rise (of bread), ferment'	xtər
Root	xəttər 'make thick, thicken'	xtər

Table 3.5: Sample primes and targets for Experiment 3 in Schluter (2013)

Results of experiment 3a (the supraliminal priming) showed significant priming effect of identity, morphology, and phonology indicating that both phonology and morphology (root) play an important role in lexical access in Moroccan Arabic. In Experiment 3b (the subliminal priming), results showed significant morphological priming but no phonological. The author concluded that phonological priming must take place in a later stage of lexical access because phonological effects were found in supraliminal but not in subliminal priming. In other experiments, Schluter (2013) also found strong effect of other types of roots such as the hollow roots, lame roots and weak roots and hence concluded that real words in Moroccan Arabic prime one another only when they share the same root. However, based on the results of Experiment 5 which showed that form 2 verbs (CəCCəC) primed by form 1 (CCəC) were faster to identify than form 1 verbs primed by form 3 (CaCCəC), the author concluded that the root is a structural unit but not an independent unit perception-wise as roots should be accessed from hearing any word in a morphological family. Apart from whether the root is an independent processing unit or not, the results of these experiments as a whole highlighted the importance of the root in lexical access in Moroccan Arabic.

Along the same lines, Ussishkin et al. (2015) conducted a series of cross-modal lexical decision tasks in order to investigate the priming effect of both root and word pattern in Maltese. They argue that Maltese is uniquely important in understanding lexical access in Semitic languages due the fact that it uses the Roman alphabet-based orthographic system which, unlike other Semitic languages' orthographic systems, encodes both consonants and vowels equally. In both Arabic and Hebrew, short vowels are not coded in the writing systems. Four experiments were conducted to investigate the effect of root and word pattern (also called binyanim) in the Maltese verbal system. Experiment 1a investigated whether prime - target pairs that belong to the same root would provide a facilitatory priming effect as a result of morphological decomposition that identifies the root and words with the same root are activated. There were 36 real word primes that were paired with real word targets. These were constructed to create three conditions(see Table 3.6): identical (e.g., *giddem* "to gnaw', morphologically (root) related (e.g., *ngidem* "to be bitten" - *giddem* "to gnaw' and unrelated (e.g., *ntasab* 'to take a seated position' - *giddem* 'to gnaw'). In addition, 36 non-word primes were paired with non-word targets. Participants heard an audible spoken prime and then saw a printed target word and their task was to decide whether the target was a word or a non-word. The results showed priming effect for both identical words and root-related words compared to unrelated ones.

Condition	Prime	Target
Identity	giddem 'to gnaw'	giddem 'to gnaw'
Root-related	ngidem 'to be bitten'	giddem 'to gnaw'
Unrelated	ntasab 'to take a seated position'	giddem 'to gnaw'

Table 3.6: Sample primes and targets for Experiment 1a in Ussishkin et al. (2015)

.

Experiment 1b investigated the effect of word pattern in the Maltese verbal system. Stimuli were similar to those in Experiment 1a except that the morphologically related words were related in terms of word pattern rather than the root (e.g., prime = *kiber* 'to grow', target = *siket* 'to be quiet' (see Table 3.7). The results of this experiment found no significant facilitatory effect of priming in the word pattern related condition. This failure to obtain a facilitatory priming for primes and targets sharing the same word pattern replicates the previous findings obtained from visual modality in Maltese (Twist, 2006). It is also consistent with a less reliable priming effect of word patterns in Arabic visual word recognition reported by Boudelaa and Marslen-Wilson (2005). However, the results from Maltese are at odds with visual masked priming in Arabic (e.g., Boudelaa & Marslen-Wilson, 2001, 2004) and Hebrew (e.g., Deutsch et al., 1998), which have obtained word pattern effect. Ussishkin et al. (2015) attribute the lack on an effect of word patterns in Maltese to the low information content of word patterns compared to roots.

Condition	Prime	Target
Identity	siket 'to be quiet'	siket 'to be quiet'
Root-related	kiber 'to grow'	siket 'to be quiet'
Unrelated	xebbah 'to assimilate'	siket 'to be quiet'

Table 3.7: Sample primes and targets for Experiment 1b in Ussishkin et al. (2015)
.

Experiments 2a and 2b were identical to Experiments 1a and 1b except that they used a subliminal priming technique created by compressing the duration of the sound files of primes. The duration of each prime was compressed to 35% of its original duration. This technique was used to determine whether the same results would be obtained with and without minimum conscious awareness of the spoken primes. The results of these two experiments replicated the results obtained from Experiments 1a and 1b. Ussishkin et al. (2015) concluded that these results highlight the importance of the consonantal root as a distinct morphological unit in Maltese and confirm previous findings from the visual modality in both Arabic and Hebrew. They also claimed that these findings provide further support for the models of morphological processing that allow morphological decomposition (e.g., Baayen et al., 1997; Baayen & Schreuder, 1999; Caramazza et al., 1988; Taft, 1988; Taft & Forster, 1975).

3.4 Methodologies used in Arabic SWR research

Previous research on word recognition in Semitic in general, and in Arabic in particular, demonstrated strong effects of the consonantal root in both the auditory and visual modalities compared to a fragile effect of word pattern. The majority of studies on word recognition in Arabic have used the priming paradigm, mainly masked priming (e.g., Boudelaa & Marslen-Wilson, 2001, 2004; Mahfoudhi, 2005; Qasem, 2010) and cross-modal priming (e.g., Boudelaa & Marslen-Wilson, 2005, 2015; Ussishkin et al., 2015). The few studies that have specifically investigated SWR used lexical decision with cross-modal priming. In this technique, primes are presented auditorily and targets are presented in the form of printed words. As these findings were all obtained from the priming paradigm, the current study used a different methodology which is the visual world paradigm (VWP) with eye tracking (Cooper, 1974; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995).

The VWP has not been used to explore SWR in Arabic. Eye-tracking has been found to be an excellent method to investigate SWR. Eye movements have been found to be linked to lexical activation. When the name for a image is activated, subjects have been found to shift their attention to that image and fixate on it; moreover, participants also fixate on other related words that share phonological features with the heard word (e.g., Allopenna et al., 1998; McMurray et al., 2003) or words that share semantic features (Huettig, Quinlan, McDonald, & Altmann, 2006; Yee & Sedivy, 2006). In addition, this technology allows us to use images instead of printed words, which allows us to rule out any orthographic effects as short vowels are not always coded in Arabic writing system. Moreover, this methodology allows for fine-grained detail about the time course of activation during the process of lexical access and word recognition; whereas priming techniques typically provide details about fixed stimulus onset asynchrony (SOA)[1]. Eye-tracking has also been found to

[1]Stimulus onset asynchrony refers to the time period between prime onset and target onset (Meyer & Schriefers, 1991)

be a valuable methodology to investigate phonological, semantic, and morphological effects in lexical access (e.g., Allopenna et al., 1998; Apfelbaum et al., 2011; Huettig et al., 2006; Mirman & Magnuson, 2009; Yee & Sedivy, 2006).

3.5 The current dissertation work

This dissertation investigates SWR in Arabic and focuses on the consonantal root, as the effect of roots has been found more reliable in both the visual and auditory modalities and in both masked priming and cross-modal priming. Specifically, the experiments examine whether Arabic words derived from the same consonantal root are linked in the mental lexicon and hence are co-activated during SWR. However, as Arabic words derived from the same root share both phonological and semantic properties, it is hard to know whether the effect comes from the root as an independent morphemic unit or whether the effect comes from the phonological and semantic overlap between these words. Therefore, it is important to separate these effects by exploring the effects of the mere phonological and semantic overlaps in SWR in words that do not belong to the same root. Only then can the effect of the root be explored and compared to the effects found for phonological and semantic overlap.

Two eye tracking experiments were designed to explore the effects of phonological, semantic, and root activation in SWR in Arabic. In each study, participants were presented with a display of four images: a target, a competitor, and two unrelated images. Participants were asked to click on a target image while their eye movements and reaction times (RT) were recorded. The assumption was that eye movements to the different types of images would reflect degrees of lexical activation. In both Experiments 1 and 2, the activation of lexical candidates was expected to result in more fixations directed to the target images than to competitor and unrelated images, and potentially with more fixations to competitors than to unrelated images. Experiment 1 explored the effects of phonology, semantics and morphology (root) in SWR in Arabic. Experiment 2 explored whether Arabic words that belong to the same root are co-activated regardless of the amount of semantic overlap between them. Finally, Experiment 2 also explored whether Arabic words that belong to the same root are co-activated regardless of the overall phonological overlap. With respect to phonology and semantics in SWR, the current research attempts to provide evidence from a less researched language: Arabic. As for the root, the present work is an attempt to explore the time course of root activation and to identify which of the models of SWR is better able to explain the patterns of activation. To summarize, the current work will attempt to answer the following research questions:

1. What is the nature of phonological, semantic and root activation in SWR in Arabic (Experiments 1 and 2)?

2. Are there graded fixation proportions that correspond to different amounts of phonological and semantic overlap between targets and competitors (Experiments 1 and 2)?

3. What is the role of the Arabic consonantal root in SWR (Experiment 2)?

4. What is the role of semantic transparency in root activation in SWR in Arabic (Experiment 2)?

5. What is the role of onset in root activation in SWR in Arabic (Experiment 2)?

6. Is the Arabic root an independent processing unit in lexical access in SWR separable from phonological and semantic factors (Experiment 2)?

7. Which models of SWR are best able to accommodate the results obtained from the current work?

Chapters 4 and 5 will report on the experiments. Chapter 6 will provide a general discussion of the results and their implications for the field of SWR.

Chapter 4

Phonological, Semantic and Root Activation in SWR in Arabic

This chapter outlines Experiment 1, in which phonological, semantic and root effects in SWR in Arabic were explored. This is the first work to use the visual world paradigm to investigate these effects. The experiment reported in this chapter is a revised version of a pilot experiment that featured 31 participants, and which was published as (Alamri & Zamuner, 2015). While this pilot experiment found differences in participants' fixations to targets in the presence of phonological, semantic and root competitors, there were a number of shortcomings in the experimental design. First, the pilot was not fully counterbalanced across different experimental lists. Second, there was no baseline condition, which made the interpretation of the results difficult at times. Lastly, the pilot was designed with three experimental blocks with the same target repeated in each block, which may have allowed participants to notice the relationship between the target and competitor over repeated presentations. Statistical analyses revealed a significant block effect, which suggests that the organization of the trials may have encouraged participants to use strategic response strategies.

In order to overcome these shortcomings, the pilot experiment was redesigned. First, a baseline was added. In this condition, each target image appeared with three images of unrelated distractors. Distractors in the baseline condition did not overlap phonologically or semantically with targets. Moreover, they did not belong to the same consonantal root or word pattern of targets and hence were morphologically unrelated. One of the three distractors in each baseline trial was arbitrarily assigned as a pseudo-competitor so that I could compare it with phonological, semantic and root competitors. Second, although the stimuli used in the preset study were identical to the stimuli used in the pilot study, I used four separate lists in the present study, ensuring that that each participant saw each target only once. This was done in order to avoid the strategic responses used by participants in the pilot study, which was most probably a result of the presenting of the same target three times in the same list (more details about the stimuli are discussed in section 4.2.2 below).

4.1 Overview

The review of previous research on word recognition in Arabic revealed ample evidence for root activation obtained from the visual modality using masked, cross-modal and auditory-auditory priming (e.g., Boudelaa & Marslen-Wilson, 2001, 2004, 2005). Although previous research on SWR in Arabic is sparse compared to that of the visual modality, the few studies that have investigated SWR in Arabic (Boudelaa & Marslen-Wilson, 2000, 2015; Schluter, 2013; Ussishkin et al., 2015) have obtained similar results regarding the strong priming effect of the Arabic root. The results obtained from the cross-modal priming studies by Boudelaa and Marslen-Wilson (2000, 2015) and from auditory lexical decision tasks Schluter (2013) found that root-related prime/target pairs produce facilitatory effects. Mere phonological overlap between prime-target pairs produced inhibitory effects or no effects at all. This direction of effect has been explained as evidence that Arabic words are separated into their constituent morphemes during SWR, and the extraction of the root results in the activation of all the words derived from that root. Words that are phonologically but not root or semantically-related to a given word are not involved in this decomposition process, and hence their phonological overlap takes the process in a direction that results in inhibitory effects. Prime/target pairs that are semantically-related (but not root-related) produce a facilitatory priming effect; however, the effect is not comparable to that of the root-related prime/target pairs. Therefore, the authors concluded that the root effect was a genuine morphological effect that could not be attributed to phonological overlap or semantic relatedness. Rather they explained the strong effect of the Arabic consonantal root as evidence for the root as a lexical unit that plays a role in the process of SWR in Arabic.

The results of the auditory-auditory priming study by Ussishkin et al. (2015) on SWR in Maltese showed that lexical access is facilitated by the consonantal root. Targets were recognized significantly faster when they were primed by root-related primes than when they were primed by unrelated primes. This facilitatory effect was present whether the prime was masked (subliminal) or non-masked (supraliminal). The authors concluded that root-related words are automatically accessed and activated early in the process of SWR in Maltese. This was also taken as evidence that the root has a cognitive status used in accessing words in the mental lexicon. These results from the visual and spoken modalities on word recognition in Arabic backed by similar results from Hebrew (Deutsch et al., 1998; Frost et al., 1997) are in agreement with the decomposition models of complex word recognition discussed in Chapter 3 that feature morphological decomposition processing.

The present study used the visual world paradigm with eye tracking, which has not been previously used to investigate SWR in Arabic. This methodology allowed me to examine the finely-grained details of the time course of activation. Participants were presented with a display with four images: a target, a competitor (phonological, semantic or root competitor) and two unrelated images. In the baseline condition, each target was presented with three unrelated words (not phonologically, semantically or root-related to the target. However, one of these unrelated words was used as a control. This is referred to as "the pseudo-competitor" throughout the course of this dissertation. Participants were asked to click on the target image while their eye movements in reaction to the images and response times (RT) were recorded. Assuming that eye movement to relevant images reveals lexical activation, the activation of lexical candidates is expected to result in more fixations directed to the target images and the images of phonological, semantic and root competitors than to unrelated images. Previous research using the eye tracking methodology has found that participants' eye movements are more likely to be drawn to phonological competitors of a given word than to phonologically unrelated words (Allopenna et al., 1998; Dahan, Magnuson, & Tanenhaus, 2001; Tanenhaus et al., 1995). The timing of fixations to phonological competitors has been found to reflect the positioning of phonological overlap between targets and competitors. That is, if they overlap at the onset position (e.g., *beaker/beetle*), fixation occurs early in the time course. When the overlap is at final position (e.g., *beaker/speaker*), fixation occurs later in the time course (Allopenna et al., 1998; McMurray et al., 2003). These findings suggests that eye tracking features high temporal sensitivity that can show a close time-locking between the unfolding of the acoustic information of auditory stimuli and eye movement reactions to the visually presented phonological competitors (Yee & Sedivy, 2006).

Eye-tracking has also been found to be sensitive to semantic activation. Competitors that were semantically but not phonologically related to targets have been found to be fixated upon more than semantically and phonologically unrelated distractors (Apfelbaum et al., 2011; Yee & Sedivy, 2006). This indicates that eye tracking is able to detect activation of semantic information during lexical access and that it is not limited to reflecting phonological activation based on acoustic overlap between targets and competitors. However, semantic activation occurs later than onset activation because semantic activation logically requires some acoustic information before it starts (Yee & Sedivy, 2006).

With regard to morphological activation, eye tracking has been used to explore morphological decomposition in complex words (Paterson, Alcock, & Liversedge, 2011). These studies have found that reading a given derived word (e.g., *marshy*) facilitated the recognition of the stem of that word (e.g., *marsh*) that appeared a few words later in the sentence, indicating that the stem was activated in the course of processing the morphologically related word that appeared earlier in the sentence. Similar results were obtained from morphological decomposition in compound words (Andrews, Miller, & Rayner, 2004; Pollatsek, Hyönä, & Bertram, 2000). These results suggest that complex words are decomposed during word recognition and words related to their constituent morphemes are also activated; however, the activation might be a function of semantic transparency (Paterson et al., 2011).

The current work used eye tracking to explore phonological, semantic and root (morphological) activation in SWR in Arabic. Based on fixation proportions and response times averaged across participants, trials and time, the current study aimed to investigate the following research questions:

1. Are there graded fixation proportions that correspond to different amounts of phonological and semantic overlap between targets and competitors across conditions?

2. To what extent does the presence of a phonological competitor, semantic competitor or root competitor affect the proportion of fixation to the target compared to a baseline competitor?

3. Are there significant differences between the proportions of fixation to the competitors between the four conditions?

4. Are there significant differences in RTs to the target between the four conditions?

4.2 Method

4.2.1 Participants

Participants were 28 adult native speakers of Arabic who were recruited from the Saudi Students Club in Ottawa (25 males, 3 females, mean age = 23, range 17–43). All participants had Arabic as their L1 and English as their L2, as determined by questionnaire (see Appendix A). The participants were from different regions of Saudi Arabia and spoke slightly different dialects, however, all the words that were used in this study were present in their dialects as confirmed by the familiarity rating discussed below. All participants reported that the age at which they started to learn English was 12 years, except three participants who reported the ages 7, 8, and 9 years. Their self-reported proficiency in English ranged from fair to very good. All participants reported that they use Arabic every day. The participants daily use of Arabic ranged from 20 to 80% with an average of 51.45% per day. All participants reported having normal or corrected-to-normal vision, normal hearing and no reading problems. Three additional participants were tested, but the data was not included due to poor calibration measurements. All participants were compensated with CAD $10.

4.2.2 Materials

Stimuli were fifteen quadruplets of Saudi Arabic nouns (see Table 4.4). More specifically, 15 target words, 15 phonological competitors (also called cohort competitors, which are words that start with the same two segments of the target words but do not belong to the same root and are not semantically related to the target words), 15 semantically-related competitors (but not root or phonologically related to the target), and 15 root competitors (words that belong to the same consonantal root including the first consonant, but do not share the second segment). An additional 30 unrelated words were selected that did not overlap semantically or phonologically with the targets or the competitors. Stress and syllabicity were partially controlled for. The majority of words were polysyllabic with the first syllable stressed (see full list of stimuli Table 4.1; primary stress is marked with apostrophes). To reduce the probability of participants noticing a tendency for competitor words to be phonologically, semantically or morphologically (root) related to targets, 20 filler items were included in which the target words were unrelated to any of the corresponding items in the visual display. The auditory stimuli were recorded by a male native speaker of Saudi Arabic (average length = 789.06 ms SD = 70.25; average pitch = 111.91 Hz; amplitude adjusted to be between 65 and 70 dB). ‘

Target	Phonological	Semantic	Root	Baseline	Unrelated 1	Unrelated 2
muˈdarris	ˈmusaddas	tˤabˈʃu:rah	ˈmadrasah	tufˈfa:ħah	ˈʔarnab	ˈnaʤm
‘teacher’	‘pistol’	‘chalk’	‘school’	‘apple’	‘rabbit’	‘star”
sajˈja:rah	ˈsajf	ˈkafarah	ˈsajr	ˈtˤa:wilah	ˈʤabal	ˈtimsaħ
‘car’	‘sword’	‘tire’	‘treadmill’	‘table’	‘mountain’	‘crocodile’
ˈʃubbak	ˈʃurbah	ˈba:b	ˈʃabakah	ˈʕasal	ˈna:r	ˈqird
‘window’	‘soup’	‘door’	‘net’	‘honey’	‘fire’	‘monkey’
ˈʃa:riʕ	ˈʃaʤarah	ˈrasˤi:f	ˈʃiraʕ:	ˈmilʕaqah	ˈbasˤalah	ˈnamlah
‘street’	‘tree”	‘curb’	‘coat rack’	‘spoon’	‘onion’	‘ant’
ˈħisˤa:n	ˈħiba:l	ˈsarʤ	ˈħisˤn	ˈqalam	ˈʃaʕar	ˈri:ʃah
‘horse’	‘ropes’	‘saddle’	‘castle’	‘pen’	‘hair’	‘feather’
ˈfurʃah	ˈfurn	ˈbujah	faˈra:ʃah	ˈʤundi:	ˈʕajn	ˈtˤamatˤim
‘brush’	‘stove’	‘paint’	‘butterfly’	‘soldier’	‘eye’	‘tomato’
ˈbaħr	ˈbaqarah	ˈsafi:nah	ˈbaħħa:r	ˈki:s	ˈϑuʕban	ˈku:rah
‘sea’	‘cow’	‘ship’	‘sailor’	‘bag’	‘snake’	‘ball’
ˈʃari:tˤ	ˈʃamʕah	muˈsaʤʤil	ˈʃurtˤi:	ˈmasʤid	ˈʤubnah	ˈʕanz
‘cassette’	‘candle’	‘tape recorder’	‘policeman’	‘mosque’	‘cheese’	‘goat’
ˈkatib	ˈkajk	ʤaˈri:dah	ˈkita:b	ˈdˤifdaʕ	ˈqufl	ˈmatˤ ar
‘writer’	‘cake’	‘newspaper’	‘book’	‘frog’	‘lock’	‘rain’
ˈħa:filah	ˈħaʤar	ˈqitˤa:r	ˈħaflah	ʤʕu:d	ˈmitˤraqah	ˈxaru:f
‘bus’	‘stone’	‘train’	‘party’	‘oud’	‘hammer’	‘sheep’
ˈxa:tim	ˈxaʃabah	ˈħalaq	ˈxatm	ˈtˤa:biʕah	ˈwardah	ˈfi:l
‘ring’	‘piece of wood’	‘earring’	‘stamp’	‘printer’	‘flower’	‘elephant’
ˈtˤair	ˈtˤabil	ˈʕuʃʃ	ˈtˤa:ʔirah	ˈsikki:n	ˈʤazmah	ˈxija:r
‘bird’	‘drum’	‘nest’	‘airplane’	‘knife’	‘shoe’	‘cucumber’
ˈʃa:ħin	ˈʃams	ˈʤawwal	ˈʃuħnah	ˈsˤa:firah	ˈburtugal	ˈʕaqrab
‘charger’	‘sun’	‘cellphone’	‘shipment’	‘whistle’	‘orange’	‘scorpion’
ˈkaʃʃa:fah	ˈkalb	ˈxajmah	ˈkaʃf	ˈʤazarah	ˈsaħab	ˈmawzah
‘boyscout’	‘dog’	‘tent’	‘register’	‘carrot’	‘cloud’	‘banana’
ˈxajtˤ	ˈxass	ˈʔibrah	ˈxajja:tˤ	ˈkursi:	ˈsamakah	ˈriʤl
‘thread’	‘lettuce’	‘needle’	‘tailor’	‘chair’	‘fish’	‘leg’

Table 4.1: Stimuli list for Experiment 1 (primary stress is indicated by the APA mark (ˈ) before stressed syllable).

4.2.2.1 Familiarity ratings as a measure of word frequency

Due to the unavailability of a word frequency count dictionary for Saudi Arabic, a familiarity rating task consisting of 138 words was developed as an online survey and was sent by email to 30 individuals recruited from the Saudi Students Club in Ottawa (21 males and 9 females; mean age = 28; age range: 19–42). None of these participants took part in the actual experiment. These individual were from different parts of Saudi Arabia and spoke different dialects. They were asked to rate the words based on familiarity (how often they hear and/or read the words). The rating scale was as follows: (1) I do not know this word, (2) I know this word but never encountered it, (3) I know this word but rarely encounter it, (4) I know this word and sometimes encounter it, and (5) I know this word and I usually encounter it. From these ratings, only a subset of words that were rated 3.5 or above were used in the study. A one-way ANOVA showed no significant difference among the seven types of words ($F(6,\ 98) = 0.47$, $p > 0.82$; see Table 4.2). Tukey pair-wise comparisons showed no significant differences between word groups (see Table 4.3).

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
variable	6.000	0.044	0.007	0.476	0.825
Residuals	98.000	1.520	0.016		

Table 4.2: 1-way ANOVA to compare average familiarity rating for all word types.

	Difference	Lower	Upper	p
Root-Target	0.018	-0.119	0.155	1.000
Semantic-Target	-0.002	-0.139	0.135	1.000
Phonological-Target	0.013	-0.124	0.150	1.000
Baseline-Target	0.044	-0.092	0.181	0.958
Unrelated1-Target	0.058	-0.079	0.195	0.864
Unrelated2-Target	0.020	-0.117	0.157	0.999
Semantic-Root	-0.020	-0.157	0.117	0.999
Phonological-Root	-0.004	-0.141	0.132	1.000
Baseline-Root	0.027	-0.110	0.164	0.997
Unrelated1-Root	0.040	-0.097	0.177	0.975
Unrelated2-Root	0.002	-0.135	0.139	1.000
Phonological-Semantic	0.016	-0.121	0.152	1.000
Baseline-Semantic	0.047	-0.090	0.184	0.947
Unrelated1-Semantic	0.060	-0.077	0.197	0.841
Unrelated2-Semantic	0.022	-0.115	0.159	0.999
Baseline-Phonological	0.031	-0.106	0.168	0.993
Unrelated1-Phonological	0.044	-0.092	0.181	0.958
Unrelated2-Phonological	0.007	-0.130	0.144	1.000
Unrelated1-Baseline	0.013	-0.124	0.150	1.000
Unrelated2-Baseline	-0.024	-0.161	0.112	0.998
Unrelated2-Unrelated1	-0.038	-0.175	0.099	0.981

Table 4.3: Pair-wise comparisons of average familiarity rating for word types

4.2.2.2 Visual stimuli rating

The visual stimuli were clipart images taken from free commercial clipart databases and online image banks. The images were selected to be as prototypical as possible to the word they were associated with based on Saudi Arabian norms. All target and competitor images were presented to five native speakers of Arabic also recruited from the Saudi Students Club who did not participate in the study. These individuals were shown the images and asked to describe each image with one word. They were also instructed to write the first two names that came to their mind if an image could be described by two names. All except two images were named correctly by at least four out of the five individuals. These two images were replaced by new images and shown to the original five individuals and an additional five other participants and were then named correctly by all 10 participants.

4.2.2.3 Semantic ratings

A semantic relatedness rating task was conducted to make sure that only the semantic competitors and root competitors were semantically related to the target and not the phonological competitors and unrelated items. Fifteen participants recruited from the Saudi Students Club in Ottawa (9 males and 6 females; mean age = 24 years; age range: 19–29 years). Participants were asked to evaluate the semantic association between targets and competitors and unrelated words. The rating scale was as follows: (1) no connection, (2) remote connection, (3) moderate connection, (4) strong connection and (5) one immediately brings the other to mind. Semantic associations between the target words and phonological competitors, baseline and unrelated groups were all rated 1 (no connection) indicating no semantic association at all. With regard to the semantic condition, only words that had a mean score of 4 or above were included as semantic competitors. Finally, the semantic association between targets and root competitors ranged from 1 (no connection) to 5 (one immediately brings the other to mind) with a mean of 2.86.

4.2.2.4 Conditions

Stimuli were used to create four conditions: baseline, phonological, semantic and root. In the baseline condition, each target image appeared with three unrelated images (recall that one of the three unrelated items was chosen to be the "pseudo-competitor" for statistical comparisons). In the other three conditions, each target image appeared with a related competitor (phonological, semantic or root) and two unrelated images. This allowed for a comparison between the three test conditions: a baseline condition in which the target image was presented with three unrelated images. In other words, it was possible to measure the fixation proportions and RTs to targets in the absence of any related competitors.

The order of the trials was manually pre-randomized, and four ordered lists were created so that the same target was not presented twice within the same list. In each list, there were 15 test trials counterbalanced in terms of condition . For example, one participant saw the first target presented with phonological competitor, another participant saw the same target presented with a semantic competitor, another participant saw the same target with a root competitor and another participant saw the same target with unrelated words only (baseline condition). Finally, the trials in each list were also randomized so that no consecutive trials were from the same condition.

4.2.3 Procedure

Participants were tested in one session, which lasted between 30 to 40 minutes. Each participant first completed a language background questionnaire (Appendix X). Eye movements were recorded using a chin rest with the Eyelink 1000 (SR Research Ltd., Canada). Monocular recording of the dominant eye of the participant (determined by the Miles-Test) was performed. Before starting the experiment, the eye tracker was calibrated using a nine-point calibration grid and all participants had calibration validity measurements of less than a 1.00-degree visual angle. Three additional participants were tested but their data was not included due to difficultly in calibrating the machine. Drift correction was performed between every trial in the form of a central fixation dot to account for shifts in eye position.

The experiment was presented in a sound-attenuated booth, using a LCD Arm Mount EyeLink 1000 (modified Desktop Mount), presented on a 22 Samsung Syncmaster 2233RZ monitor and flexible LCD Arm. Participants were seated with their eyes 60 cm from the monitor and with their head stabilized by a chin rest. Their elbows rested on the table and in their dominant hand they had a mouse that allowed them to select target images. The sampling rate of the eye tracker was 500 Hz. The experiment was programmed and presented using Experimenter Builder.

Each trial began with drift correction in the form of a central fixation dot to account for shifts in eye position. This fixation dot also served as a prompt for all trials. Once the participant looked at this dot, the experimenter pressed a key to prompt the trial. For each trial, four images appeared on the screen (Figure 4.1). An auditory stimulus of the target word was played 500 ms into the trial. The auditory stimulus was an isolated word, i.e., not included in a carrier sentence. Participants were instructed to click on the target word. Participants received colour feedback (red= incorrect response, green= correct response) upon clicking on an image. Participants had 2225 ms to provide a mouse press response, after which the trial ended and the screen changed to a central fixation dot. All trials consist of a target word (e.g. *furʃah* 'brush'), a competitor (e.g. *faraʃah* 'butterfly'), and two unrelated distractors (e.g. *ʕajn* 'eye' - *t^{ʕ}amat^{ʕ}im* 'tomato'; see Figure 4.1 for an example display). The location of the four images on the screen was manually randomized across trials.

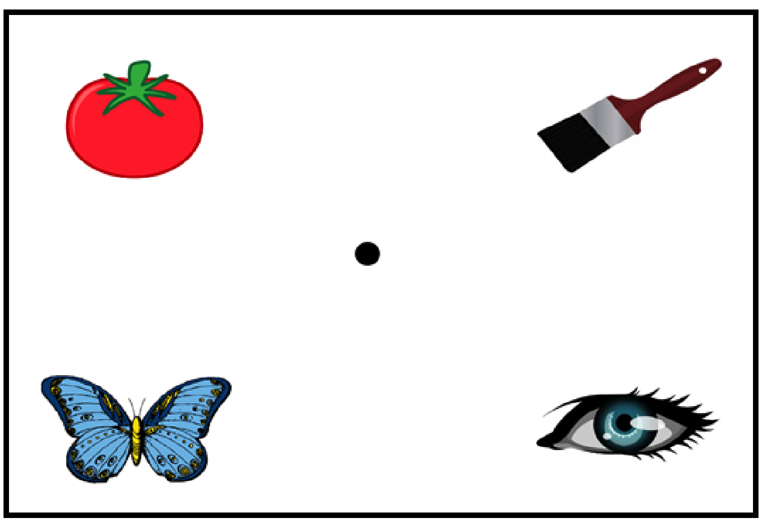

Figure 4.1: Sample display from Experiment 1 (root condition). The target object (*furʃah* "brush' is root-related to one of the other objects in the display (*faraʃah* "butterfly'. The other two objects (*ʕajn* "eye" - *t^{ʕ}amat^{ʕ}im* "tomato' are unrelated phonologically and semantically to the target and its competitor.

Proportional fixation times to the four areas of interest (each 200x200 pixels) were automatically recorded and later analyzed with DataViewer software (SR Research, version 1.11.1) and R (version 3.2.3). Before beginning the experimental task, participants completed five practice trials to ensure compliance with the task instructions. In these practice trials, a target was displayed with three unrelated items similar to the baseline condition. In total, each participant was tested on a total of 30 trials (5 practice trials + 15 experimental and baseline conditions + 10 filler trials).

4.2.4 Predictions

It was predicted that in all the phonological, semantic and root conditions, competitors would attract more fixations than to the pseudo-competitor of the baseline condition. Therefore, fixation to targets in the baseline condition was expected to be higher than fixation to targets in all the other conditions. Fixation to targets in the phonological condition was predicted to be affected by the presence of an onset competitor and fewer fixations to targets were expected early in the time course. A delay in semantic activation is expected as it require some phonological access before it start. With regard to the root condition, it was predicted that fixation to targets should be more affected by the presence of root competitors than by the presence of a phonological competitor or semantic competitors because root competitors shared both phonological and semantic information with targets. In addition, it was predicted that the participants would show shorter RTs in the baseline condition compared to other conditions. It was also predicted that they would show longer RTs in the root condition than in the phonological or semantic conditions. The facilitatory effects found in these conditions were not predicted because the design of the current research is different from that used in the priming paradigm.

	Target	**Competitor**	RTs
Experimental vs. Baseline	More looks to targets in the baseline than in the phonological, semantic and root competitors due to the presence of related competitors which is not the case in the baseline condition.	Fewer looks to baseline "pseudo-competitor" than to competitors in all experimental conditions.	Shorter RTs in the baseline condition than in all experimental conditions.
Phonological vs. Semantic	Fewer looks to phonological targets early in the time course and more looks to the semantic target. The opposite is expected later in the time course.	More looks to phonological competitors early in the time course and to semantic competitors later in the time course.	RTs may not significantly differ.
Phonological vs. Root	More looks to phonological targets than to root targets.	Fewer looks to phonological competitors than to root competitors.	Shorter RTs in the phonological condition.
Root vs. Semantic	More looks to semantic targets than to root targets.	Fewer looks to root competitors than to semantic competitors.	Shorter RTs in the semantic condition.

Table 4.4: Predictions for Experiment 1.

4.3 Results

This section reports and discusses the results of the two types of data that were obtained from this eye tracking experiment: proportional eye fixation data and RT data. The fixation data were analyzed by looking at the amount of fixation directed to different images in each display across the test trials. The RT data were analyzed by measuring the time between the onset of the spoken target word and the time at which the participant clicked on the target image (one of four images). The results of these analyses are discussed below.

4.3.1 Analyses of Eye Tracking Data

A Python script was used to extract the fixation data from word onset + 2000 ms in 20 ms time bins, which were then collapsed into 100 ms time bins. The purpose of using this Python script was to eliminate the possibility of human error in extracting and splicing the time bins. Consistent with how eye tracking data are analyzed in the field, the first 200 ms after word onset are excluded from analysis as this time is required for planning and launching a saccade (Matin, Shao, & Boff, 1993; Salverda, Kleinschmidt, & Tanenhaus, 2014). In addition, consistent with analyses in the field, individual participant data in a time bin was removed from the analyses if there was no fixation to any of the four interest areas. For example, if a participant did not look at any of the images during the time bin of 200–300 ms after word onset, that participants data for that time bin was excluded from analysis. Practice trials and filler trials were not included in the analyses.

Figure 4.2 shows the average proportions of fixation to targets, competitors, and unrelated distractors (an average of two distractors per trial) for all conditions. It also shows that looking to the target images peaks approximately 1200 ms after word onset, and dropped as participants then visually inspected the rest of the display. Fixation patterns helped identify the relevant time window to be included in the analyses (200 ms to 1200 ms after word onset), and this technique is considered standard practice in the field. This figure also shows graded competition effects of the related competitors across the three conditions and how the degree of competition differs based on the amount of linguistic properties shared with targets (i.e., phonological, semantic, or root; see Figure 4.2).

Growth curve analyses (GCA; Mirman, 2014) were used to analyze differences in target and competitor fixations across conditions. GCA is a variant of multi-level regression modelling that uses time as a predictor in the model to analyze the effect of conditions on the rate of change in fixation proportions over time (Mirman, Dixon, and Magnuson, 2008; Mirman, 2014). GCA fits the orthogonal power polynomial terms which provide

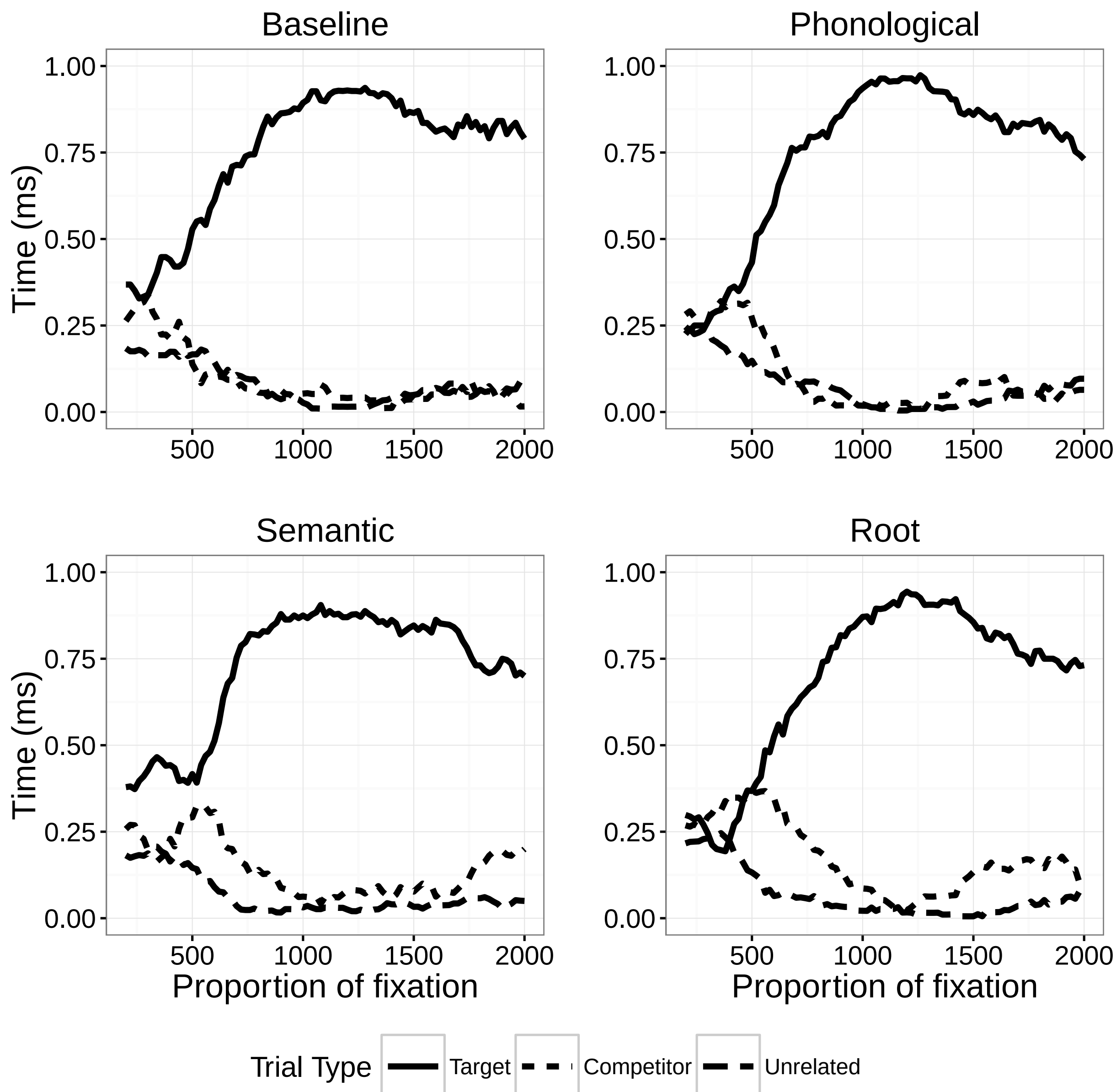

Figure 4.2: Fixation to targets, competitor, and unrelated for all conditions

discrete analyses for fixation to time data to model the fixation curve parameters. VWP data are the proportions of fixations at different time bins. These fixations (within the same condition) are not completely independent values, i.e., the likelihood of looking at an image is not independent at each time bin, but is related to where the eye was fixated in the previous time bin. Thus, the proportion of fixation at time A is not fully independent of the proportion of fixation at time B within the same time course of the same trial. Employing time as a predictor of fixation changes provides a rigorous means of analyzing time course data and overcome the gaps involved in analyzing VWP data using other methods that rely on the assumption of independent observations such as ANOVAs (Magnuson et al., 2007, p. 8).

In addition, GCA has the advantage of accounting for individual differences as it allows for separate regression models for each individual. Based on these predictors and parameters, GCA provides mean proportions of fixations to a target or a competitor at each particular point in time averaged across participants and items (Mirman, 2014; Mirman, Dixon, & Magnuson, 2008). Growth curve analyses were conducted separately for target and competitor fixations. The following two sections report on these two analyses.

A visual inspection of data indicates that fixations to targets was affected by the presence of the related competitors to different degrees. This difference can be seen from the steepness of the target fixation curves across the four conditions (see Figure 4.3), which shows fixations to targets across the phonological, semantic, root and baseline condition in the 200–1200 window. Targets in the baseline condition received the highest fixation of the four conditions. In the phonological condition, there were fewer fixations to targets early in the time course compared to the baseline condition. In the semantic condition, there are fewer fixations compared to the baseline condition later in the time course. Fixations to the targets in the root condition were the lowest, which was predicted as the root competitor shared both phonological and semantic features with the target. These differences were reflected in competitor fixation (see Figure 4.4), where the root competitors received the more fixations than the other conditions. Fixation to phonological competitors was high early in the time course. However, rates dropped down to around 400 ms after word onset. A delay in fixation to semantic competitors was also observed; however, the delay was followed by increased proportion of fixation. Fixation to pseudo-competitors in the baseline condition received the least proportions of fixation among all the conditions.

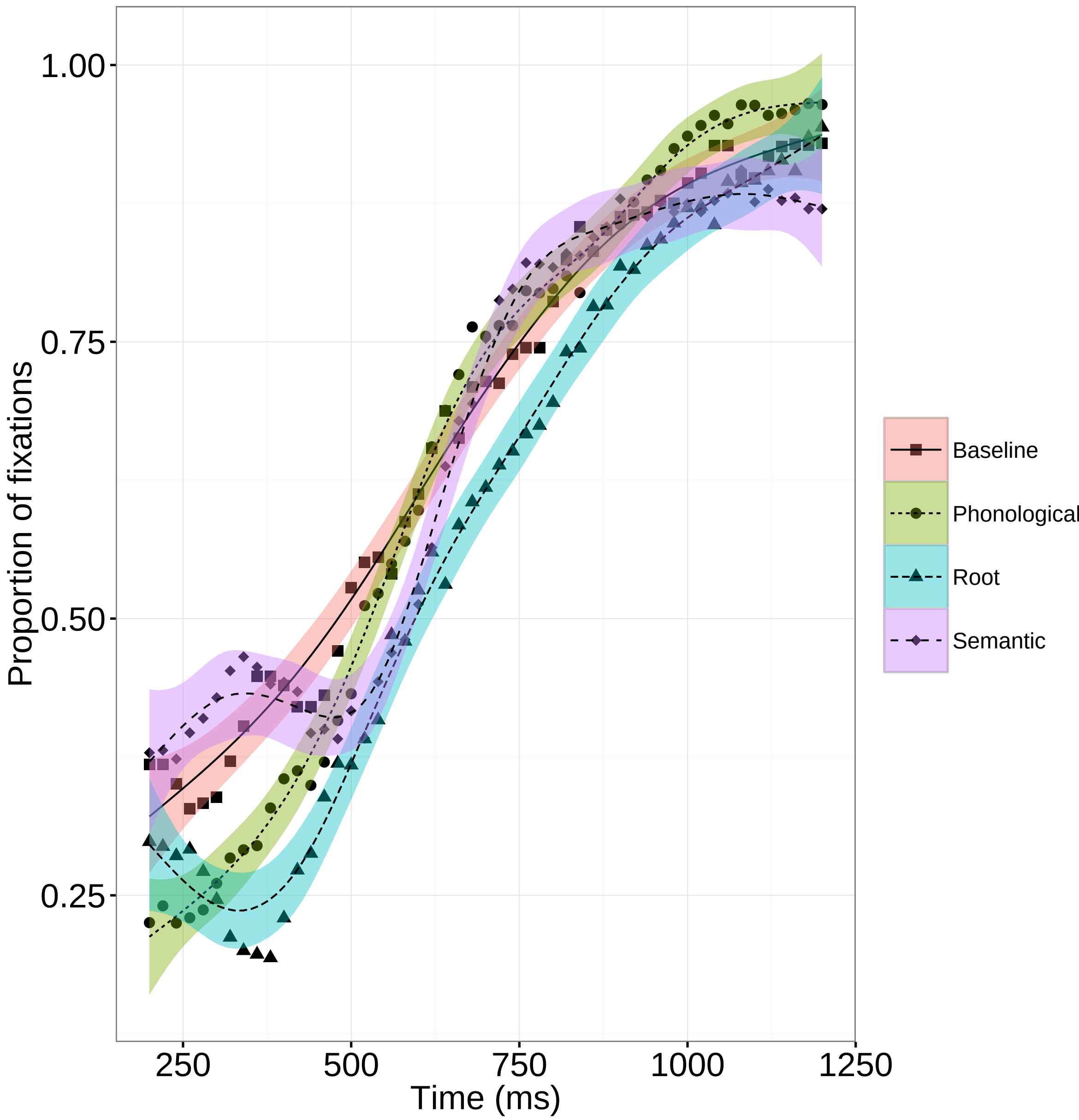

Figure 4.3: Target fixations for phonological, semantic, and root word types (LOESS smoothed lines were fit to the data)

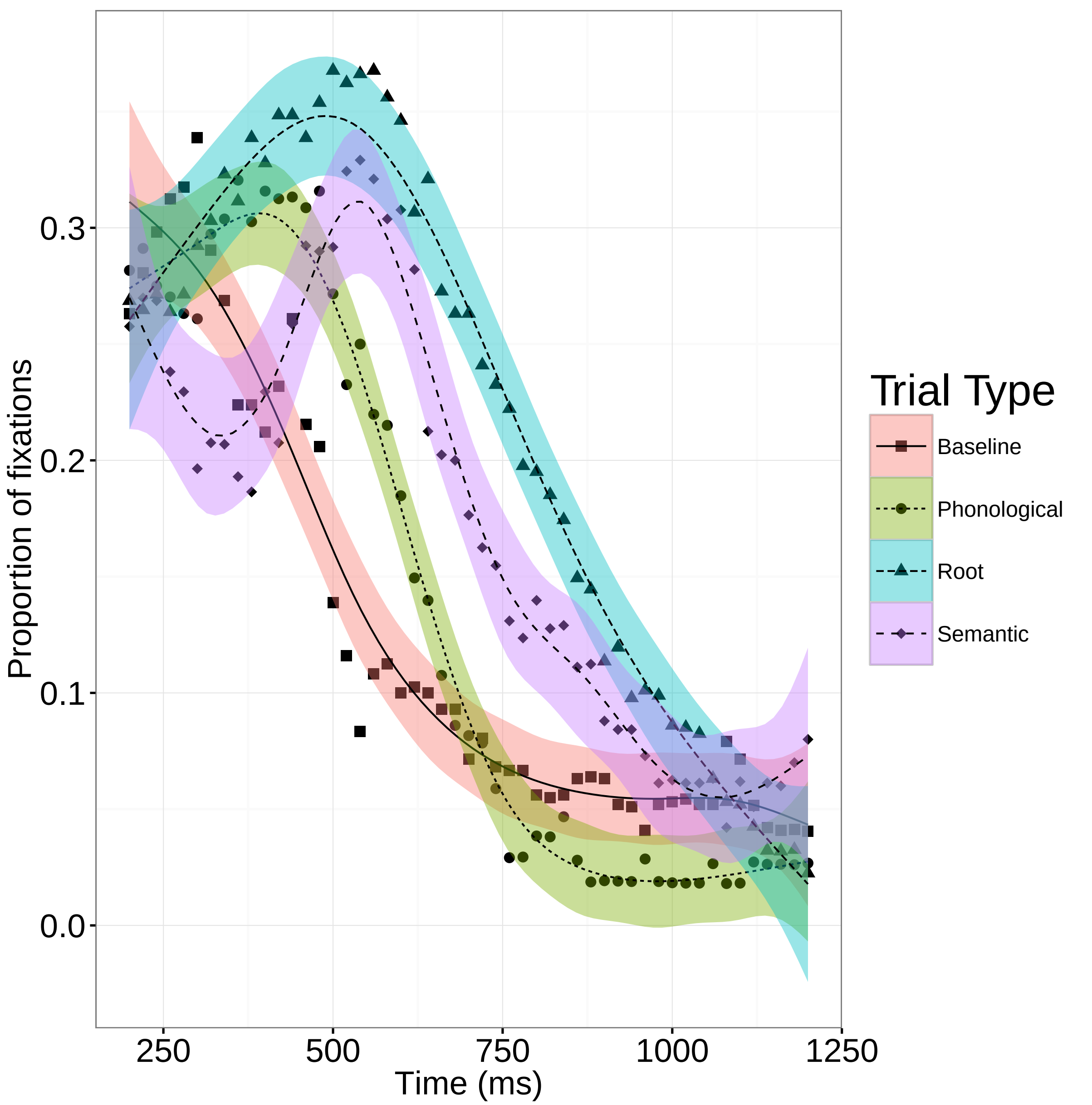

Figure 4.4: Competitor fixations for phonological, semantic, and root word types (LOESS smoothed lines were fit to the data)

In order to statistically investigate the differences between the four conditions, a quasi-logistic GCA method (Mirman 2014) was used to analyze the time course of fixation across conditions (pair-wise comparisons). Recall in Table 4.4 above, a number of statistical comparisons were planned to compare looking to targets and to competitors in the different conditions compared to baseline, and to compare looking to targets and competitors in the Phonological vs. Semantic, Phonological vs. Root, and Semantic vs. Phonological conditions. In all analyses, the overall time course of target fixations was modelled with a third-order (cubic) orthogonal polynomial and fixed effects of condition (trial type; within-participants) on all time terms. The time course was modelled in cubic terms due to the presence of three inflection points in the target and competitor fixation curves. The model also included participant random effects on all time terms and the Condition term. As the data were categorical in the sense that the target is either fixated or not, the empirical logit transformation (Barr, 2008) was used.

The analysis shows the intercept of fixation proportion as well as the linear, quadratic and cubic orthogonal polynomials. These polynomial terms are used to capture the differences in target or competitor fixations across the time course and to contribute to the shaping their curves and hence to help in explaining the time course of activation obtained from VWP studies. The intercept refers to the averaged modelled value of the y-value of the modelled curve. In other words, the intercept term indexes the average height of the curve which reflects the average overall fixation proportions across the timecourse. The linear (first-order) term reflects monotonic changes in fixation proportion and the overall angle of the slope. The quadric (second-order) term is sensitive to the rise and fall of the fixation curve (increase then decrease in fixation proportions). Finally, the cubic (third-order) term reflects the steepness of the curve around the inflection points and is sensitive to minor changes in the asymptotic tails of the curve (Mirman et al., 2008, pp. 481–483).

The following sections report quaisi-logistic GCA used to perform the pair-wise comparisons of target and competitor fixations between conditions. In each comparison, one of the conditions is treated as the reference and relative parameters are estimated using the other condition. p-values were estimated using the normal approximation for the t-values produced by the model. p-values for individual parameter estimates were calculated using normal approximation, which treated the t-value as a z-value. All analyses were carried out in R version 3.2.3 using the lme4 package (version1.1–10). Given the amount of statistical comparison, the focus will be on highlighting the differences which were related to the predictions, and on pointing out any differences that were not predicted.

4.3.2 Target and Competitor Fixations of the Experimental Conditions versus the Baseline Condition

This section describes target and competitor fixations in each of the three experimental conditions (phonological, semantic and root) relative to the baseline condition. In all comparisons, baseline is always treated as the reference condition.

4.3.2.1 Phonological versus baseline

Comparing the phonological and the baseline conditions showed that there was no effect of condition on the intercept which indicates that the overall mean of activation is similar in the two conditions. However, the comparison revealed significant differences in the curvature of the linear term and the quadratic term between the conditions (see Table 4.5). The significant difference of the conditions with regards to the linear term with a positive value for the phonological condition indicates that the fixation slope in the phonological condition is steeper than in the baseline condition (see Figure 4.5). This indicates a faster rate of change in fixating the target in the phonological condition. The significant difference with regard to the quadratic term with a negative value for the phonological curve indicates that the phonological curve reached its maximum and started to drop later than the baseline curve. This suggests that there was an inhibitory effect on looking to the target caused by the presence of phonological cohort competitors in the phonological condition, result in a relatively slower recognition.

	Estimate	Std.Error	t-value	p-value
(Intercept)	1.677	0.253	6.625	0.000
Linear	16.895	0.904	18.697	0.000
Quadratic	-2.311	1.052	-2.197	0.028
Cubic	-1.750	0.679	-2.576	0.010
Condition	-0.222	0.254	-0.874	0.382
Linear:Condition	3.722	0.598	6.227	0.000
Quadratic:Condition	-1.235	0.590	-2.095	0.036
Cubic:Condition	0.166	0.583	0.284	0.776

Table 4.5: Target Fixation: Empirical Logit GCA Results for Baseline (the reference condition) versus Phonological

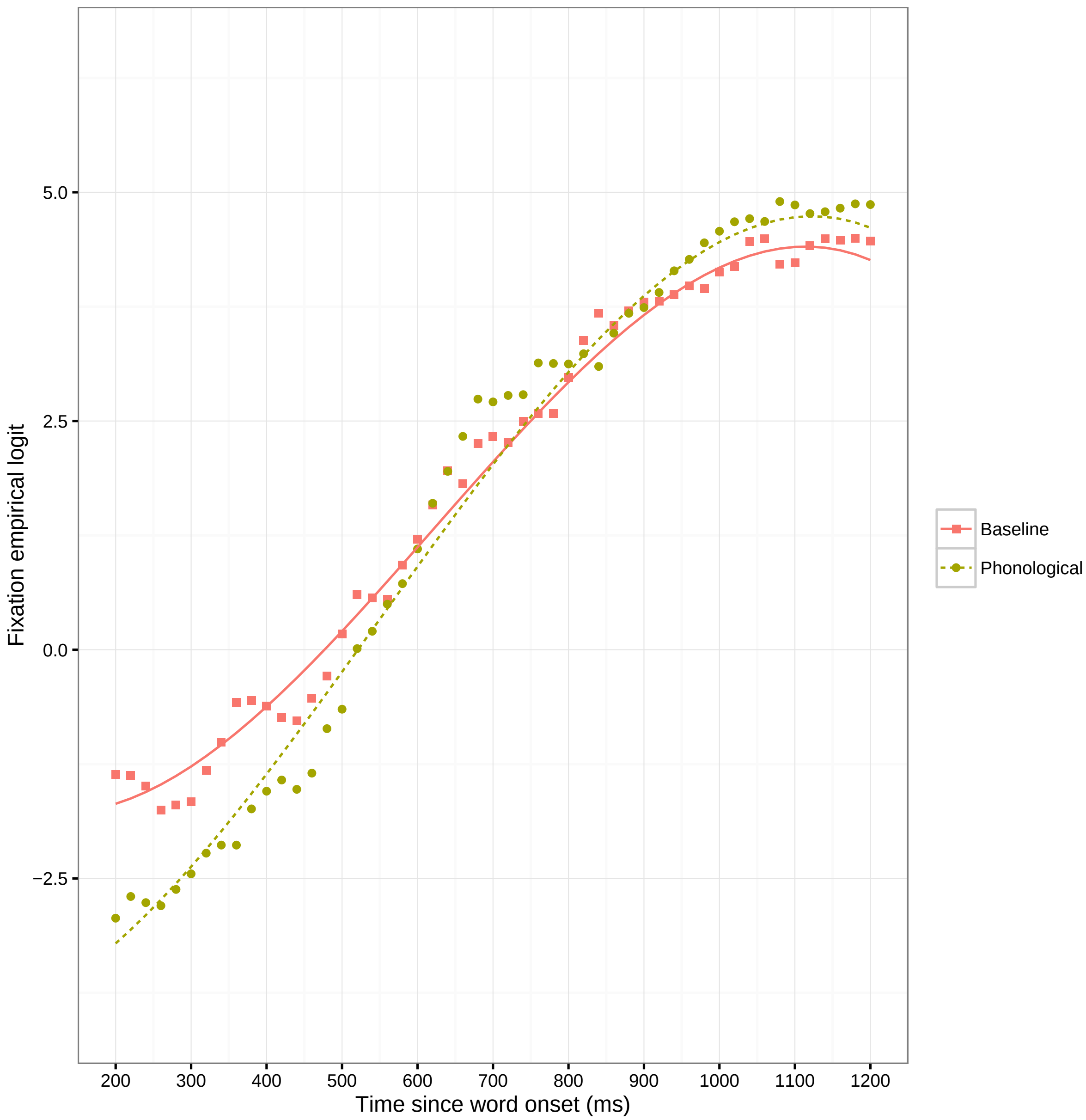

Figure 4.5: Target fixation: observed data (symbols) and GCA model fits (lines) for Baseline versus Phonological

For competitor fixation, significant differences between the phonological and baseline conditions were captured by the linear and cubic terms (see Table 4.6). By analyzing Figure 4.7, we can see that the competitors in the phonological condition received more fixations in the first portion of the time window. This higher activation of the phonological competitor early in the time course reflects the phonological overlap between targets and competitors, which was present in the first two or three initial segments. Competitor fixation decreased as the auditory stimulus mismatched the phonological representations of the competitor.

These results are in line with what was predicted. Fixation to targets in the phonological condition was affected by the presence of onset competitors. This effect was also reflected in competitor fixation. Phonological competitors were fixated more than the baseline pseudo-competitor. The fixation to phonological competitors mirrored the acoustic overlap between the auditory stimuli and competitors. That is, as participants heard the auditory stimuli, they fixated on onset competitors more than on unrelated items. The increase of fixation to the phonological competitors started as early as 200 ms, whereas the decrease occurred around the 500 ms as the incoming acoustic segments started to mismatch the onset competitor. These results are in line with previous literature showing high fixation to onset competitor in SWR (Allopenna et al., 1998; Dahan et al., 2001; Tanenhaus et al., 1995).

	Estimate	Std.Error	t-value	p-value
(Intercept)	-3.797	0.130	-29.297	0.000
Linear	-7.113	0.921	-7.725	0.000
Quadratic	1.890	0.732	2.582	0.010
Cubic	1.316	0.540	2.434	0.015
Condition	0.196	0.225	0.871	0.384
Linear:Condition	-2.710	0.471	-5.759	0.000
Quadratic:Condition	-0.492	0.464	-1.060	0.289
Cubic:Condition	2.073	0.459	4.518	0.000

Table 4.6: Competitor Fixation: Empirical Logit GCA Results for Baseline (the reference condition) versus Phonological

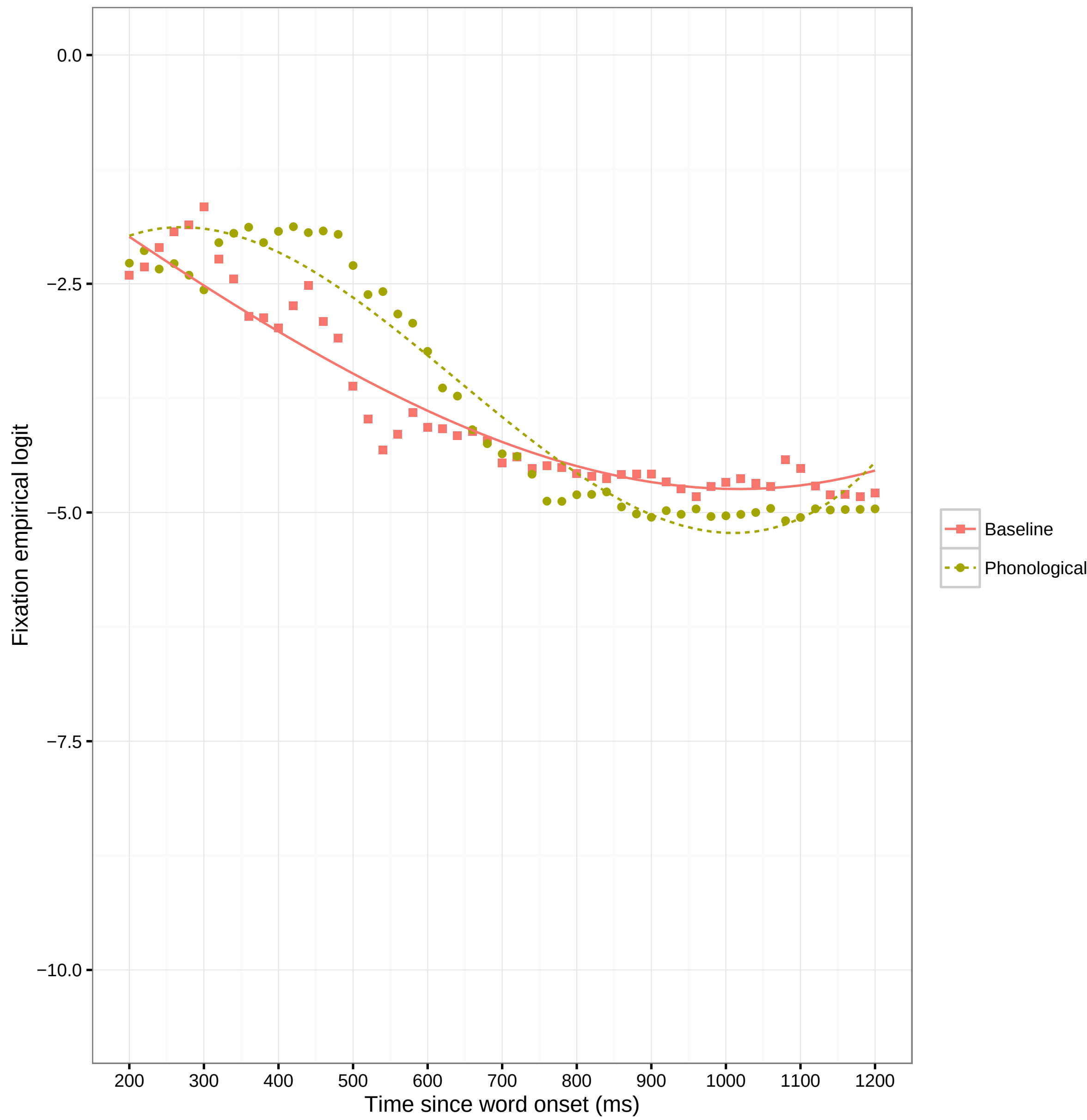

Figure 4.6: Competitor fixation: observed data (symbols) and GCA model fits (lines) for Baseline versus Phonological

4.3.2.2 Semantic versus baseline

GCA results of comparing target fixation proportions in the semantic and baseline conditions showed no significant effect of condition on the intercept. No linear or quadratic differences were found on the slopes of the two conditions. However, a significant effect was captured by the cubic term (see Table 4.7). This difference indicates that there were more inflections (rises and falls) in the semantic curve than in the baseline curve, especially at the tails. Figure 4.7 shows that the fixation proportion curves for both conditions were similar for most of the time course, except at the tails. Although it is difficult to explain the effects captured by the cubic terms cognitively, these rises and falls in the semantic curve can be understood as an effect of the presence of a semantically-related competitor.

	Estimate	Std.Error	t-value	p-value
(Intercept)	1.780	0.211	8.457	0.000
Linear	14.463	0.980	14.762	0.000
Quadratic	-1.468	1.123	-1.307	0.191
Cubic	-2.949	0.782	-3.771	0.000
Condition	-0.046	0.358	-0.127	0.899
Linear:Condition	-0.692	0.650	-1.065	0.287
Quadratic:Condition	-0.356	0.636	-0.560	0.575
Cubic:Condition	-1.550	0.629	-2.465	0.014

Table 4.7: Target Fixation: Empirical Logit GCA Results for Baseline (the reference condition) versus Semantic

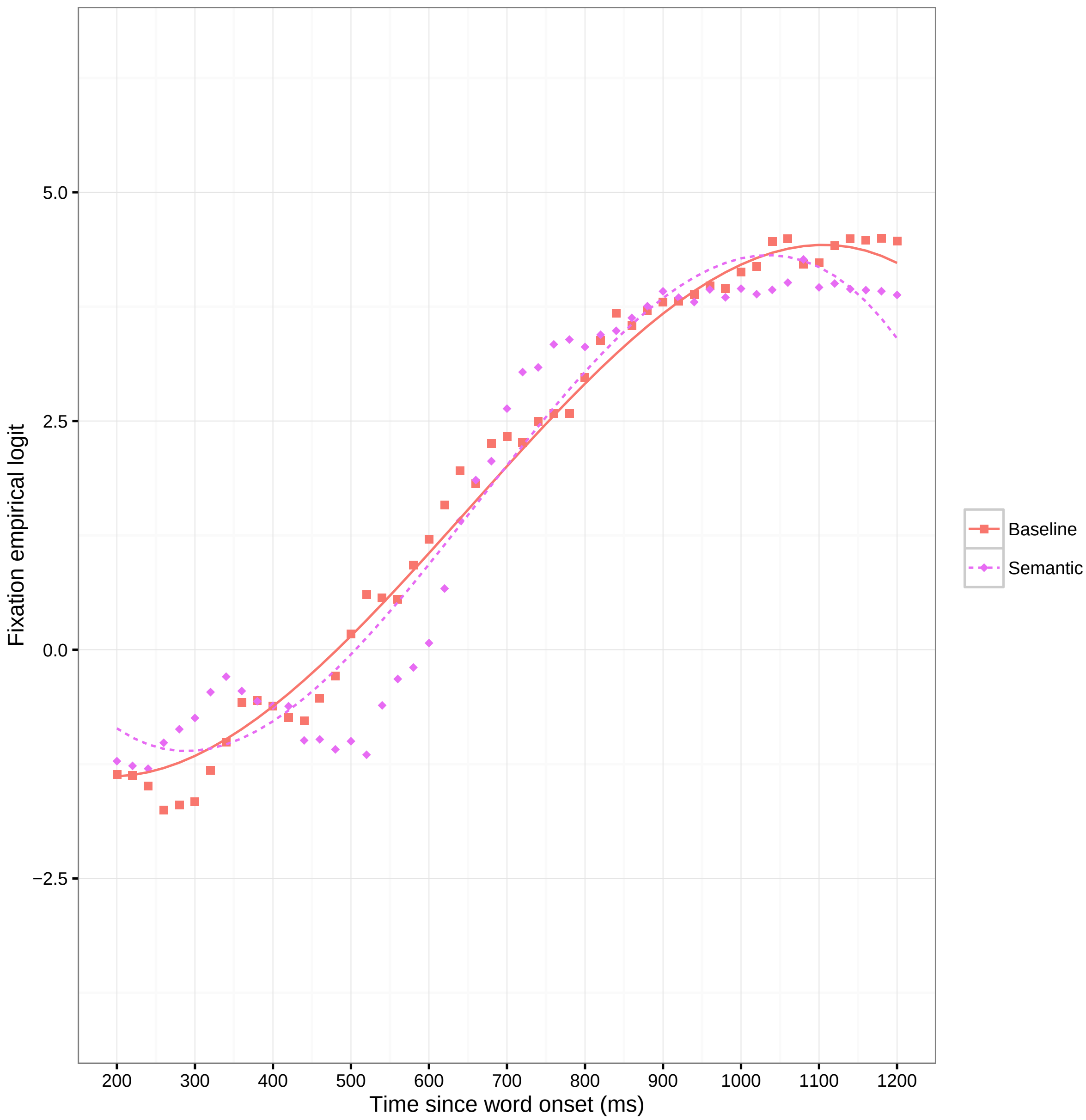

Figure 4.7: Target fixation: observed data (symbols) and GCA model fits (lines) for Baseline versus Semantic

As for competitors, the difference was clearer (see Table 4.8). GCA results showed that there was a near significant effect of condition on the intercept. There was also a significant difference in curvature captured by the quadratic term, which is a term sensitive to the centre-driven inflection point in a u-shaped curvature. Figure 4.8 shows the increase followed by decreases in the centre of the curve, creating a downward inverted-U-shaped parabolic curve. The results also showed that there was a significant effect on the cubic terms with a negative value for the semantic curve, which is indicative of more inflections in the semantic curve. Semantic competitors received higher activation than baseline competitors, particularly between the 400 and 1000 ms after word onset.

These results are in line with previous literature (Apfelbaum et al., 2011; Huettig & Altmann, 2005; Yee & Sedivy, 2006) and with the present predictions in that semantically-related competitors of a given targets are fixated more than unrelated distractors. Participants' fixation to semantic competitors started to increase around the 400 ms window and continued to be higher than fixation to baseline pseudo-competitors throughout the timecourse.

	Estimate	Std.Error	t-value	p-value
(Intercept)	-3.633	0.152	-23.893	0.000
Linear	-5.952	0.685	-8.688	0.000
Quadratic	0.448	0.790	0.567	0.571
Cubic	1.302	0.676	1.925	0.054
Condition	0.451	0.233	1.935	0.053
Linear:Condition	0.174	0.533	0.327	0.744
Quadratic:Condition	-3.427	0.521	-6.573	0.000
Cubic:Condition	1.823	0.516	3.531	0.000

Table 4.8: Competitor Fixation: Empirical Logit GCA Results for Baseline (the reference condition) versus Semantic

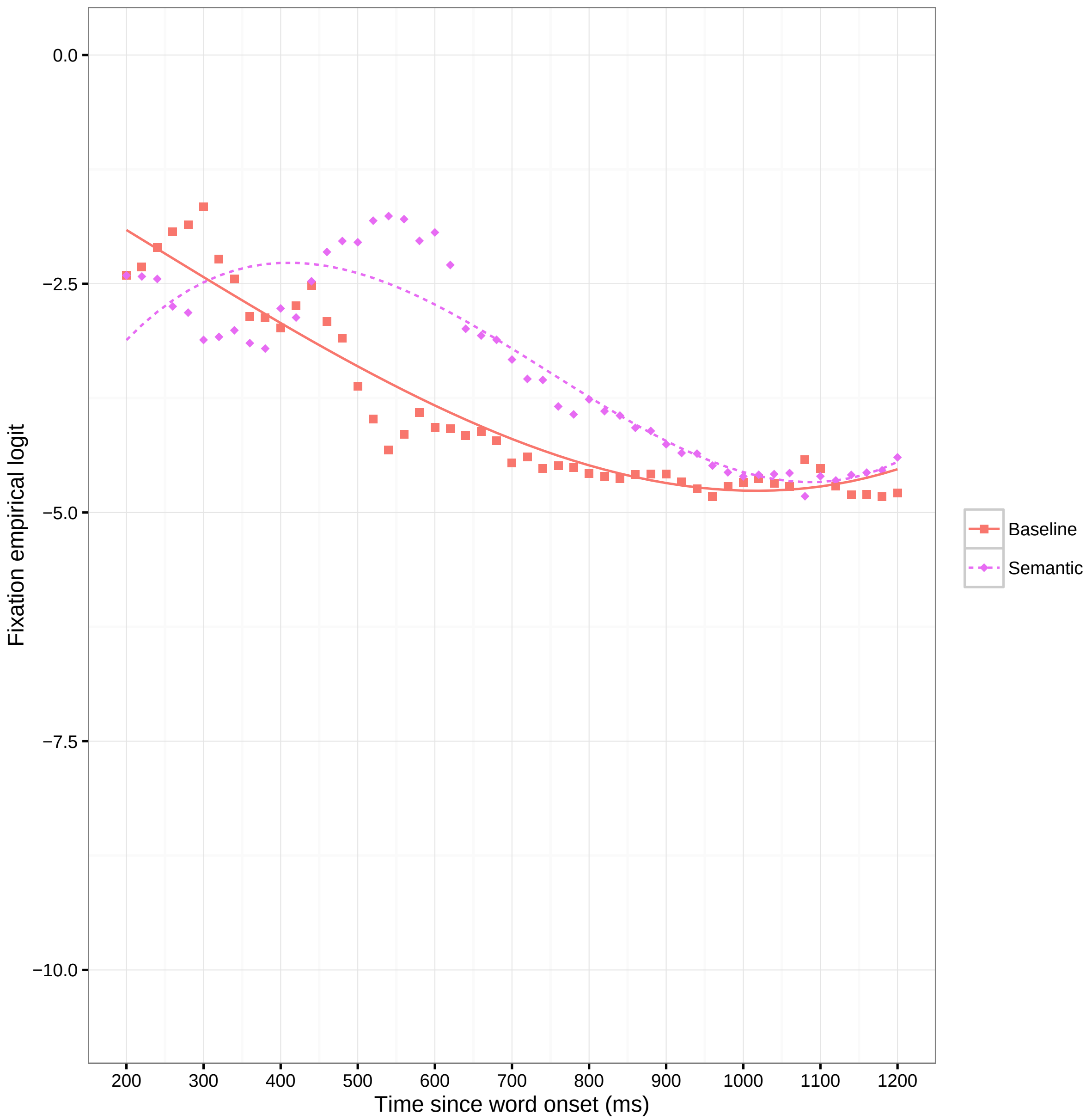

Figure 4.8: Competitor fixation: observed data (symbols) and GCA model fits (lines) for Baseline versus Semantic

4.3.2.3 Root versus baseline

The comparison of target fixation proportions in the root and baseline conditions revealed significant differences on all terms. As can be seen in Table 4.9, there was a significant effect of condition (baseline vs. root) on the intercept indicating that targets in the root condition had lower overall fixation proportions relative to the baseline conditions. There was also a significant effect of condition captured by the linear term. This significant difference on the linear term indicates a steeper curve for target fixation curve in the baseline condition compared to root condition. This suggest that targets in the baseline condition were recognized faster than targets in the root condition (see Figure 4.9). Significant differences were also captured by the quadratic and cubic terms. Figure 4.9 shows that there was decrease in target fixation early in the time course (in the 200–400 time window). This drop can be understood as a result of a strong competition caused by the presence of a root-related competitor that attracted participants' fixations.

	Estimate	Std.Error	t-value	p-value
(Intercept)	1.383	0.219	6.310	0.000
Linear	16.503	1.136	14.532	0.000
Quadratic	-1.060	1.081	-0.981	0.326
Cubic	-2.319	0.849	-2.730	0.006
Condition	-0.850	0.356	-2.389	0.017
Linear:Condition	3.042	0.643	4.730	0.000
Quadratic:Condition	1.737	0.633	2.746	0.006
Cubic:Condition	-1.607	0.629	-2.554	0.011

Table 4.9: Target Fixation: Empirical Logit GCA Results for Baseline (the reference condition) versus Root

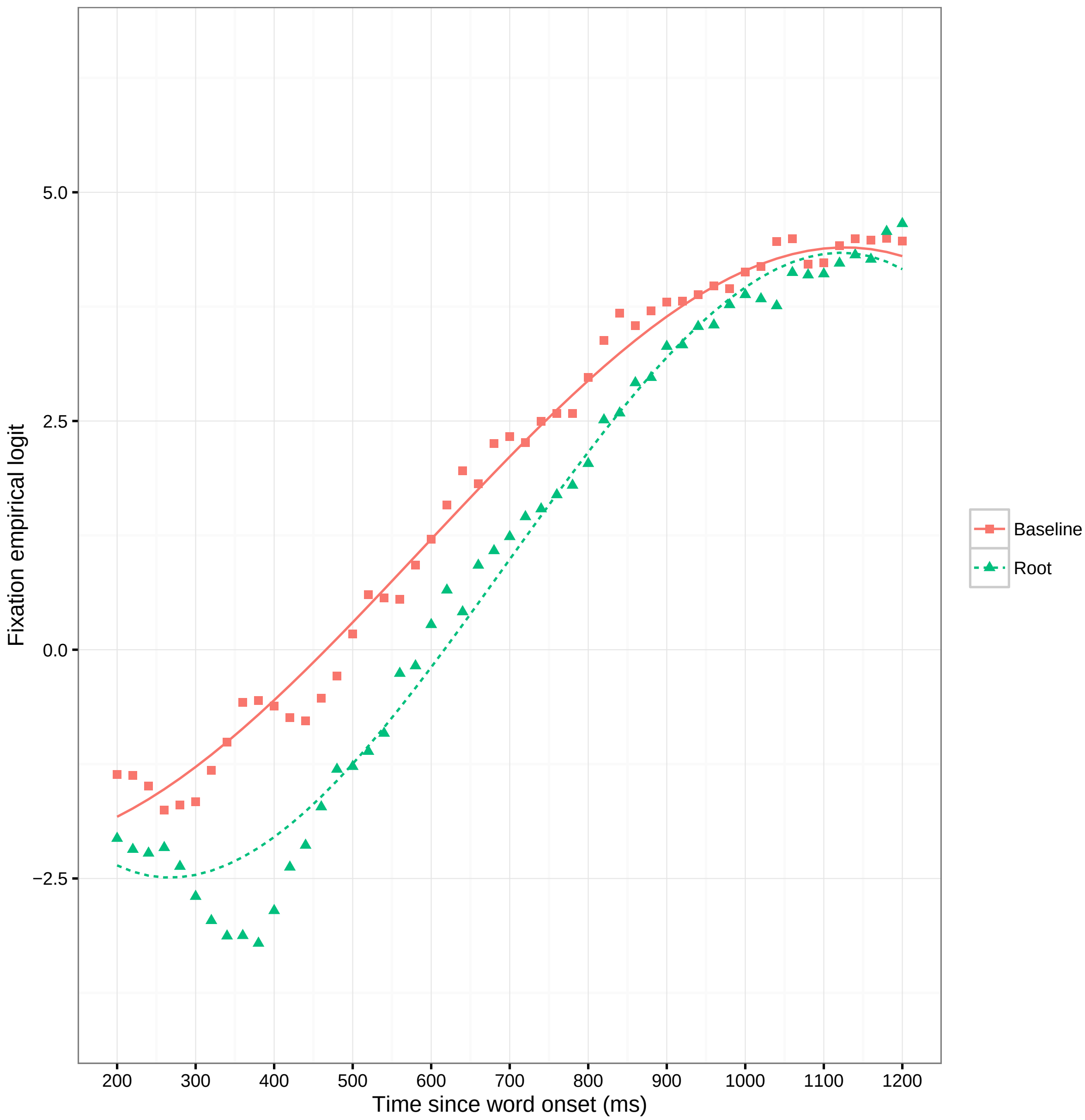

Figure 4.9: Target fixation: observed data (symbols) and GCA model fits (lines) for Baseline versus Root

The strong differences in target fixations were mirrored in strong differences between competitor fixations in the root and baseline conditions. Figure 4.10 shows a consistent and long-lasting difference in the height of the two curves. As can be seen in Table 4.10, GCA results showed significant effects on all time terms. The effect of the condition on the intercept indicated a larger overall mean of fixation to competitors in the root condition compared to the baseline condition. The effect on the linear and quadratic terms indicates a steeper curve in the root condition and reflects a faster rate of fixation to root competitors over time. These results revealed that root competitors received higher activation than baseline competitors along the time course.

	Estimate	Std.Error	t-value	p-value
(Intercept)	-3.383	0.149	-22.632	0.000
Linear	-6.781	1.289	-5.259	0.000
Quadratic	-0.331	0.909	-0.363	0.716
Cubic	1.092	0.518	2.109	0.035
Condition	0.999	0.304	3.282	0.001
Linear:Condition	-1.945	0.546	-3.562	0.000
Quadratic:Condition	-5.394	0.536	-10.054	0.000
Cubic:Condition	2.218	0.533	4.164	0.000

Table 4.10: Competitor Fixation: Empirical Logit GCA Results for Baseline (the reference condition) versus Root

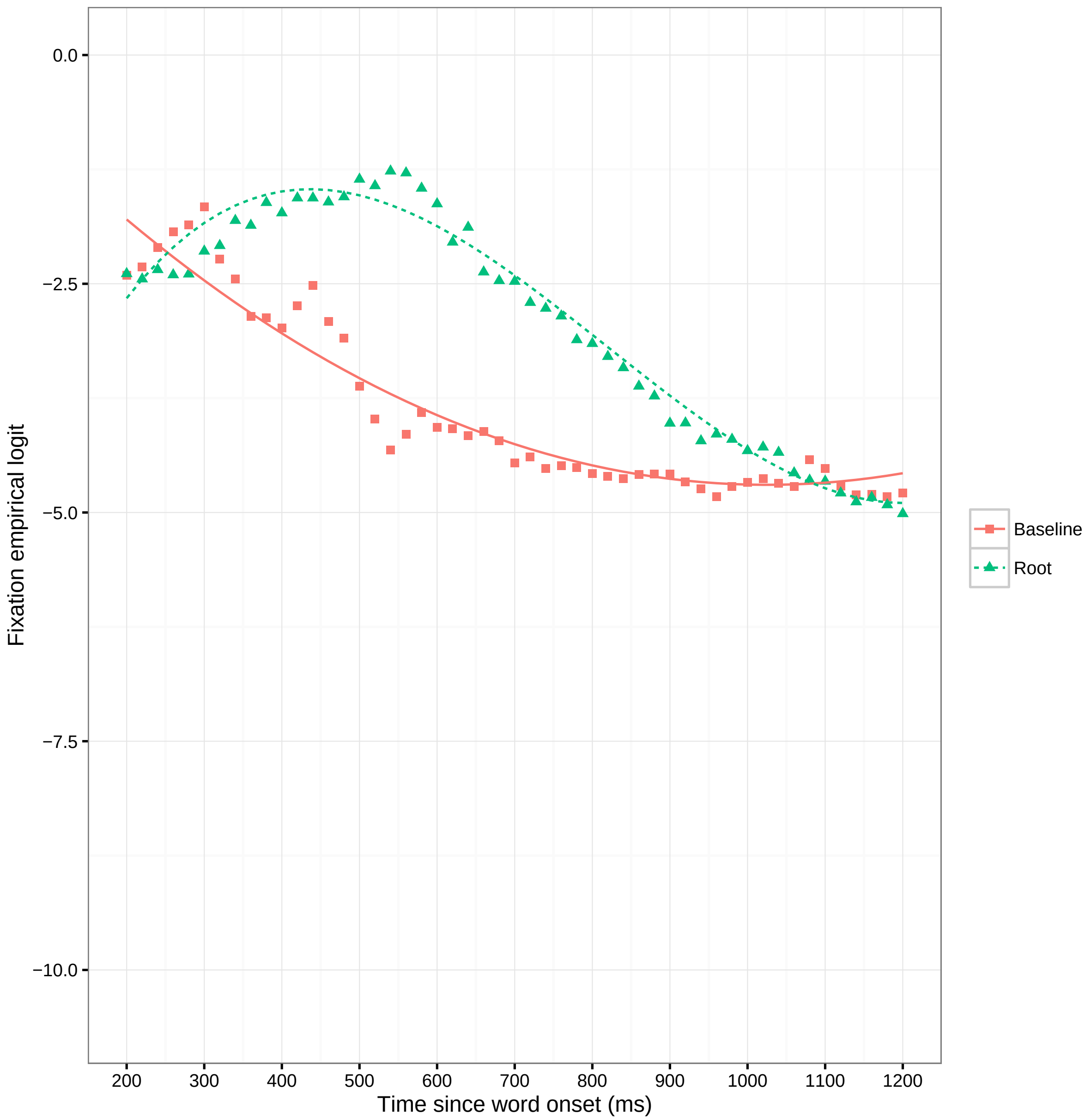

Figure 4.10: Competitor fixation: observed data (symbols) and GCA model fits (lines) for Baseline versus Root

These results are in line with the prediction that the presence of root-related competitors will cause the largest effect on target fixation. Root-related competitors influence participants' looking patterns more than the unrelated pseudo-competitors of the baseline condition. As root-related competitors shared both phonological and semantic features with targets, these results are in line with previous literature on phonological and semantic effect in drawing visual attention. They also provide support to reading studies using eye tracking methodology that have reported more gazes and longer fixation durations to morphologically related words (Andrews et al., 2004; Paterson et al., 2011). Moreover, the results converge with previous findings from the priming paradigm that have found a strong effect of Semitic consonantal roots in SWR (Boudelaa & Marslen-Wilson, 2000, 2015; Schluter, 2013; Ussishkin et al., 2015), despite the direction of the effect, which is usually dependent on experimental design. However, the strong activation of root-related competitors found in the present work can be a result of the phonological and semantic overlap with targets and not necessarily a result of morphological processing.

So far, we have seen that all three experimental conditions significantly differed from the baseline condition in both target and competitor fixations. This confirm the predictions presented in the introduction of this chapter. This also confirms the previous finding that eye tracking is able to detect phonological, semantic and morphological effects in word recognition. The next section describes the pair-wise comparisons among the experimental (phonological, semantic and root) conditions.

4.3.3 Pairwise Comparisons of Target and Competitor Fixations Between Phonological, Semantic and Root Conditions

This section describes the pair-wise comparisons of target and competitor fixations between phonological, semantic and root conditions. Although it might be repetitive to do these comparisons, especially since we have seen all of the relevant information about target and competitor fixations in the previous section, it is helpful to compare these experimental conditions directly to one another. Recall that phonological competitors are onset competitors sharing the first two or three segments with the targets (e.g., *furʃah* 'brush'/ *furn*). Semantic competitors share semantic features with targets but no phonological or root ovelaps (e.g., *furʃah* ‘brush’/ *bujah*). Root competitors are phonologically and semantically related to targets (e.g., *furʃah* ‘brush’/ *fara:ʃah* ‘butterfly’). The comparisons between these conditions show which competitor type has the largest effect on target fixation. In each of the following comparisons, the reference condition is alphabetically first.

4.3.3.1 Phonological versus semantic

The comparison between fixations to targets in the phonological and semantic conditions showed that there was no significant effect of condition on the intercept, indicating that the mean proportions of fixations did not differ between the phonological and semantic conditions. However, significant effects of condition on the linear and quadratic terms were found. The significant effect on the linear terms indicates that the rate of change in fixation to targets in the semantic condition was slower than that of the phonological condition, resulting in less steep curve (see Table 4.11). There was also a significant effect of condition captured by the cubic terms with a negative value, indicating that there were more rises and falls in the semantic curve than in the phonological curve. These results indicate that the presence of semantic competitors had more effect on the amount and speed of fixations to targets than the presence of phonological competitors. This can be visually observed from the behavioural data presented in Figure 4.11.

	Estimate	Std.Error	t-value	p-value
(Intercept)	1.663	0.207	8.033	0.000
Linear	16.399	0.968	16.945	0.000
Quadratic	-2.101	0.833	-2.522	0.012
Cubic	-2.858	0.807	-3.542	0.000
Condition	0.175	0.280	0.625	0.532
Linear:Condition	-4.452	0.615	-7.245	0.000
Quadratic:Condition	1.364	0.599	2.278	0.023
Cubic:Condition	-2.090	0.595	-3.516	0.000

Table 4.11: Target Fixation: Empirical Logit GCA Results for Phonological (the reference condition) versus Semantic

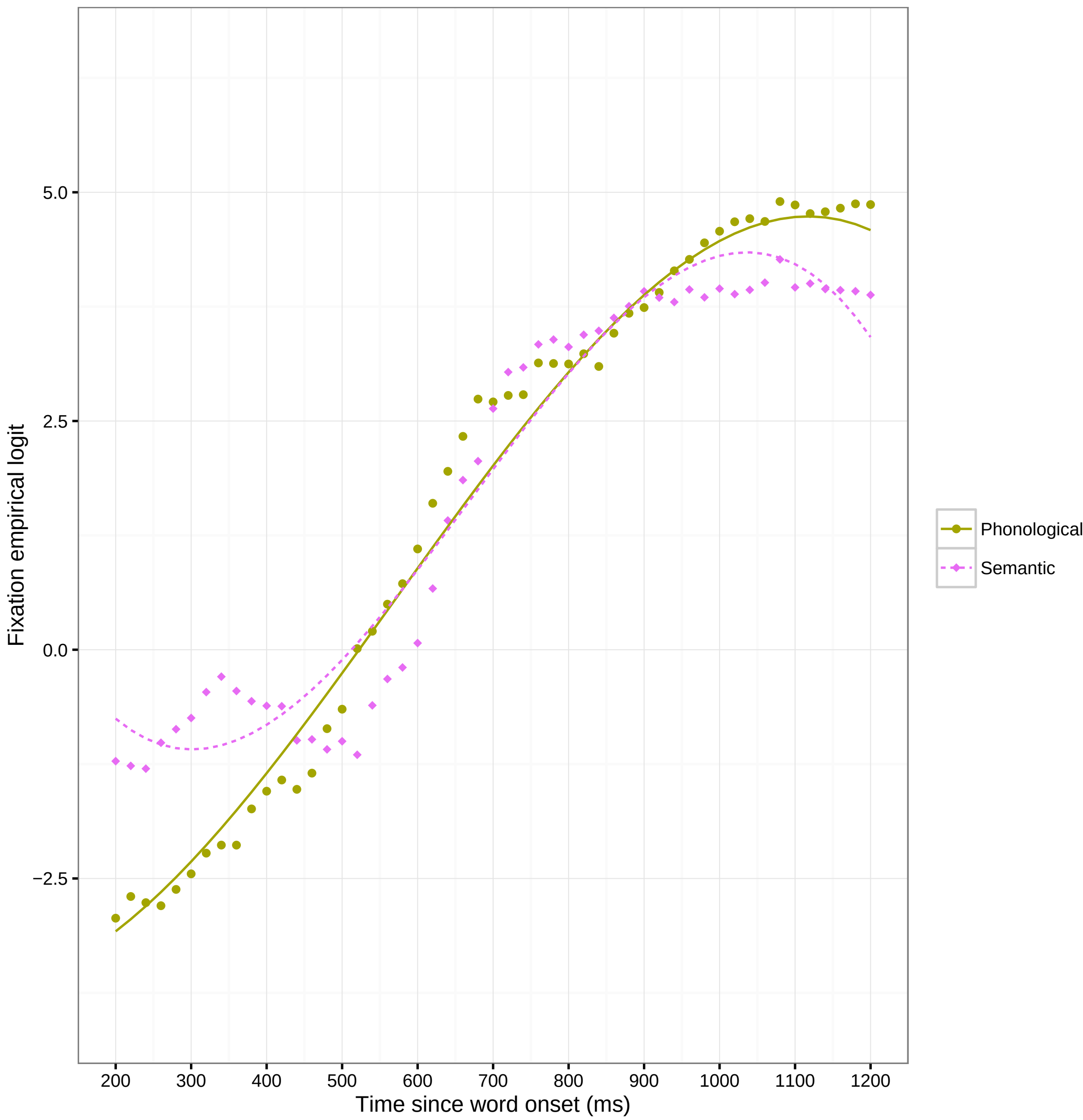

Figure 4.11: Target fixation: observed data (symbols) and GCA model fits (lines) for Phonological versus Semantic

With regard to competitor fixation, there were significant differences in curvature captured by the linear and quadratic terms. The positive value of the linear term indicates that as time progressed, the rate of change in fixation to competitors was faster for the semantic competitor compared to the phonological competitors. The negative value of the quadratic term indicates that the curve in the phonological condition started with a quicker and steeper rise to reach its maximum and then drops down creating a downward inverted-U-shaped parabolic curve earlier than the curve of the semantic condition. There was no significant difference in the cubic terms (see Table 4.12 and Figure 4.12).

	Estimate	Std.Error	t-value	p-value
(Intercept)	-3.545	0.128	-27.796	0.000
Linear	-7.278	0.641	-11.350	0.000
Quadratic	0.131	0.693	0.189	0.850
Cubic	2.230	0.709	3.147	0.002
Condition	0.315	0.227	1.387	0.166
Linear:Condition	2.457	0.516	4.760	0.000
Quadratic:Condition	-2.569	0.504	-5.101	0.000
Cubic:Condition	-0.269	0.500	-0.538	0.590

Table 4.12: Competitor Fixation: Empirical Logit GCA Results for Phonological (the reference condition) versus Semantic

These results revealed that fixations to targets were affected by the presence of phonological competitors early in the time course. Later in the time course, fixation to target was more affected by the presence of semantic competitors. However, this effect did not last long as the target fixation curve in the semantic condition reached its maximum earlier than the target fixation curve in the phonological conditions, which indicates a faster recognition of targets in the semantic condition.

The results of this comparison are in line as predicted. Phonological competitors were fixated earlier in the time course, reflecting the acoustic overlap between the auditory stimuli and the phonological representations of the competitor, which happened to be at the onset position in the study. The semantic activation started to increase at a later time bin in the time course, which was also predicted. The delay in semantic activation relative to phonological onset activation is consistent with previous research (e.g., Allopenna et al., 1998; Yee & Sedivy, 2006).

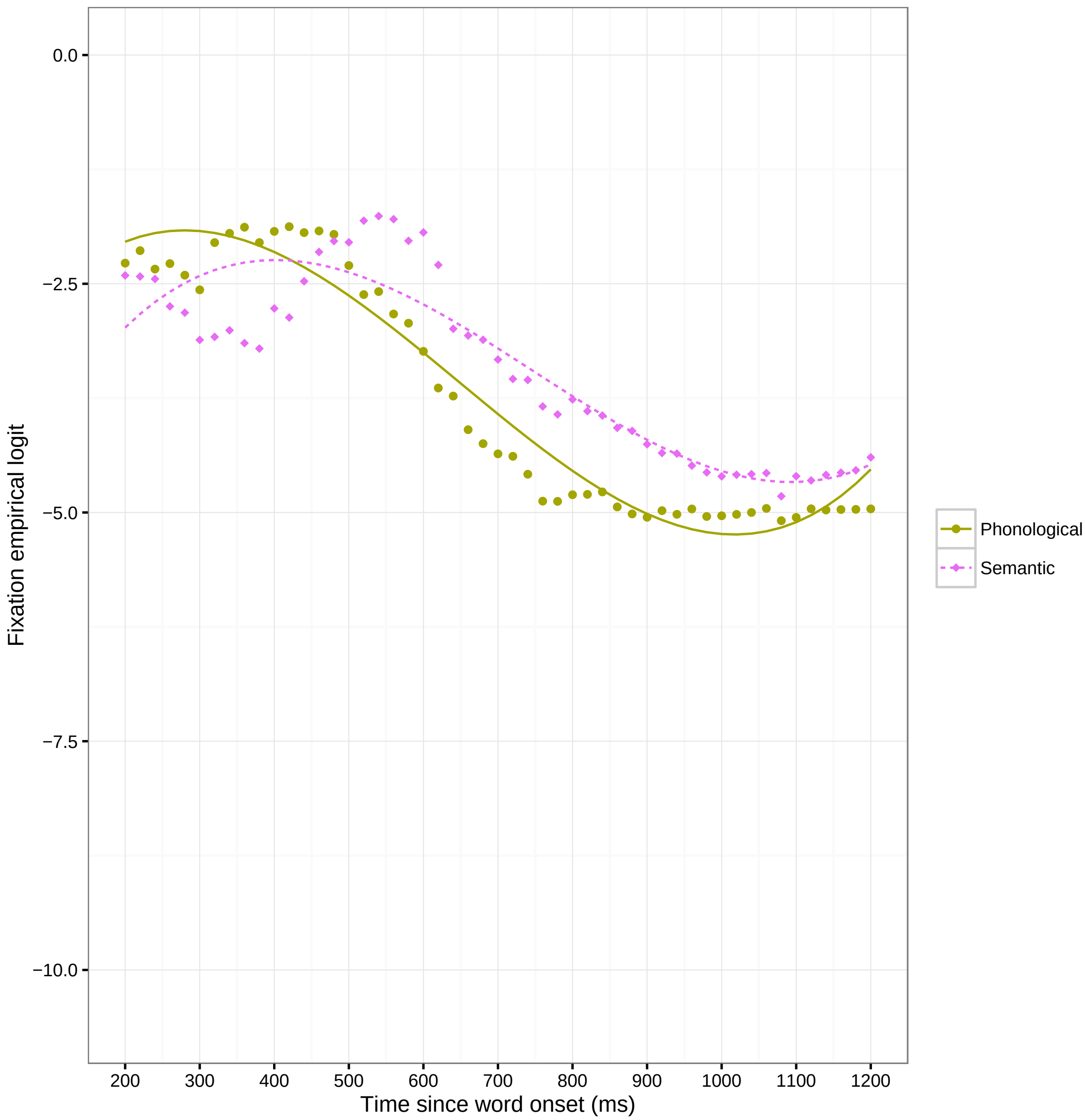

Figure 4.12: Competitor fixation: observed data (symbols) and GCA model fits (lines) for Phonological versus Semantic

4.3.3.2 Phonological versus root

GCA results showed that there was a significant effect of condition indicating larger overall fixation proportions to targets in the phonological condition than in the root condition.

The difference in fixation proportions was relatively constant throughout the time course (see Figure 4.13). This is clear from the higher target fixation curve in the phonological condition along the time course except for the very early times (200–300 ms). In addition, a significant effect was captured by the quadratic term, reflecting faster recognition of target words in the phonological condition than in the root condition. There was also a significant effect of condition on the cubic term (Table 4.13).

	Estimate	Std.Error	t-value	p-value
(Intercept)	1.242	0.195	6.357	0.000
Linear	18.300	1.185	15.441	0.000
Quadratic	-1.422	1.184	-1.201	0.230
Cubic	-2.409	0.724	-3.327	0.001
Condition	-0.654	0.307	-2.131	0.033
Linear:Condition	-0.470	0.603	-0.780	0.435
Quadratic:Condition	2.787	0.592	4.707	0.000
Cubic:Condition	-1.262	0.591	-2.135	0.033

Table 4.13: Target Fixation: Empirical Logit GCA Results for Phonological (the reference condition) versus Root

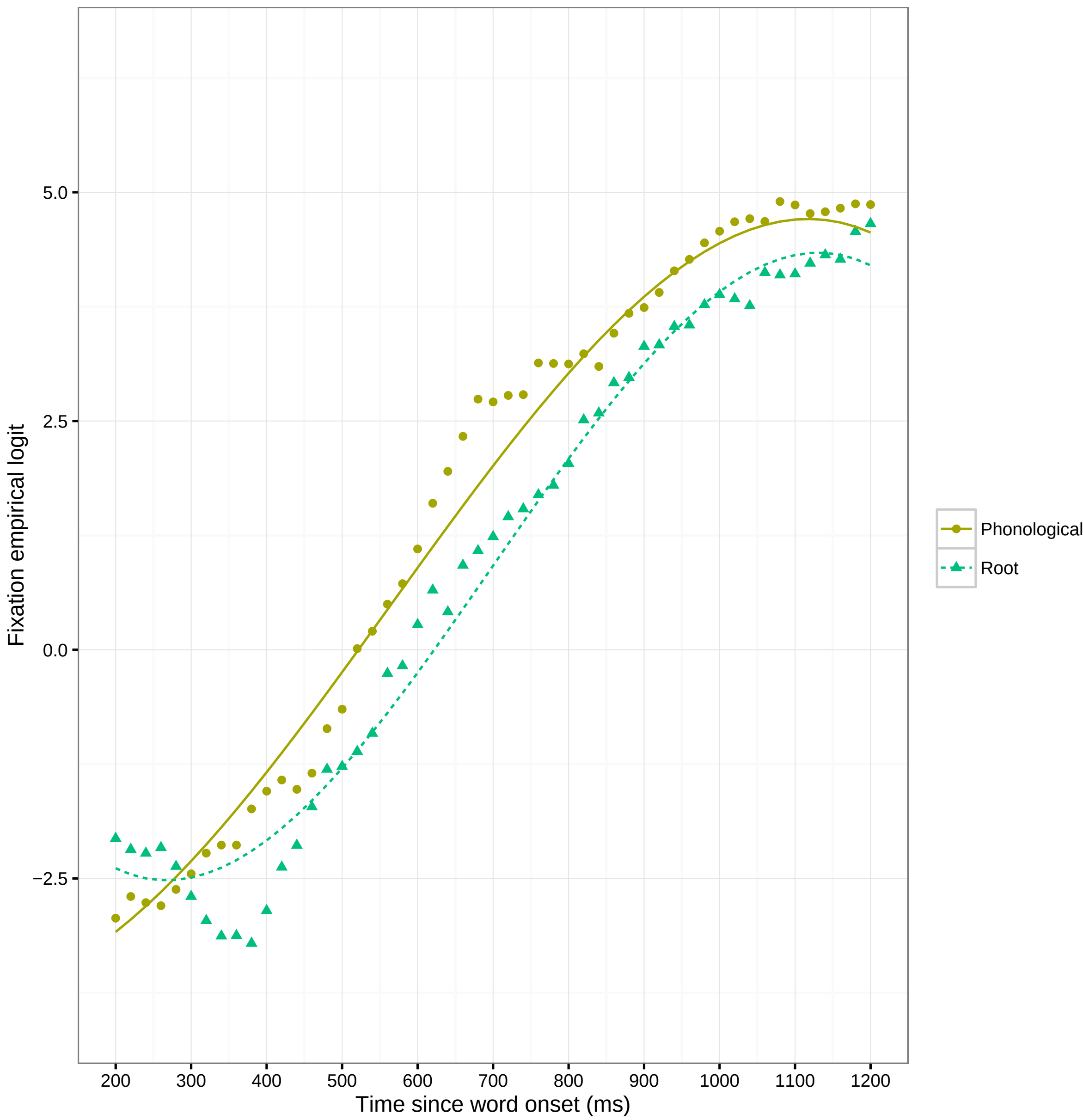

Figure 4.13: Target fixation: observed data (symbols) and GCA model fits (lines) for Phonological versus Root

The comparison of competitor fixation in the phonological and root conditions showed that root competitors received higher fixations than the phonological competitors throughout the time course, except for the very early times, as can be seen in Figure 4.14. A significant difference was also observed in the curvature captured by the quadratic terms indicating a steeper curve in the root condition. No significant differences were captured by the linear or cubic terms (see Table 4.14).

	Estimate	Std.Error	t-value	p-value
(Intercept)	-3.294	0.146	-22.589	0.000
Linear	-7.980	0.953	-8.372	0.000
Quadratic	-0.961	1.025	-0.938	0.348
Cubic	2.538	0.592	4.291	0.000
Condition	0.799	0.256	3.124	0.002
Linear:Condition	0.635	0.527	1.206	0.228
Quadratic:Condition	-4.863	0.518	-9.395	0.000
Cubic:Condition	0.079	0.516	0.153	0.878

Table 4.14: Competitor Fixation: Empirical Logit GCA Results for Phonological (the reference condition) versus Root

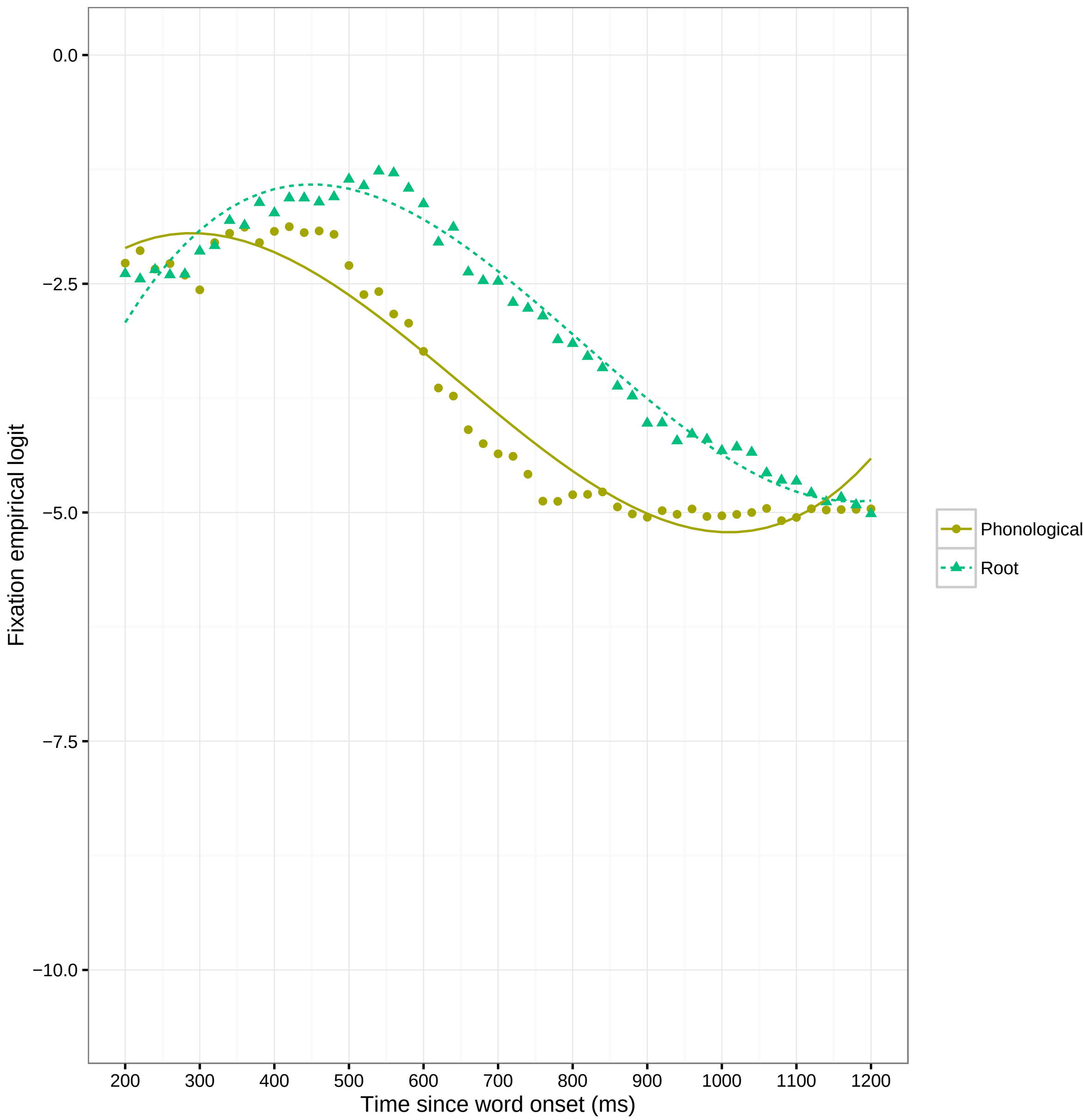

Figure 4.14: Competitor fixation: observed data (symbols) and GCA model fits (lines) for Phonological versus Root

The results were predicted as root competitors shared both phonological and semantic features with targets. Moreover, phonological overlap between targets and root-related competitors was larger than the overall phonological overlap between targets and phonological competitors. However, phonological competitors had more overlap at the onset position (phonological competitors shared the first two or three segment with targets whereas root competitors shared the first segment with targets, but mismatch with them at the second segment). These results provide support for SWR models that can accommodate phonological overlap at any point in the time course (e.g., the TRACE and NAM) and against models that require the generation of a cohort of candidate competitors based on the onset, such as the earliest versions of the cohort model.

4.3.3.3 Semantic versus root

The comparison of target fixation in the semantic and root conditions showed a significant effect of condition on the intercept, reflecting that targets in the semantic condition had a larger overall proportions of fixations compared to targets in the root condition (see Table 4.15). There was also a significant difference captured by the linear term indicating a steeper slope in the semantic condition. No significant differences were captured by the quadratic and cubic terms, indicating that the difference in fixations were relatively constant through the time course (see Figure 4.15).

	Estimate	Std.Error	t-value	p-value
(Intercept)	1.307	0.188	6.963	0.000
Linear	16.338	1.175	13.904	0.000
Quadratic	-1.039	0.903	-1.151	0.250
Cubic	-3.398	0.693	-4.903	0.000
Condition	0.861	0.353	2.438	0.015
Linear:Condition	-4.044	0.665	-6.080	0.000
Quadratic:Condition	-0.985	0.647	-1.523	0.128
Cubic:Condition	-0.995	0.644	-1.544	0.122

Table 4.15: Target Fixation: Empirical Logit GCA Results for Root (the reference condition) versus Semantic

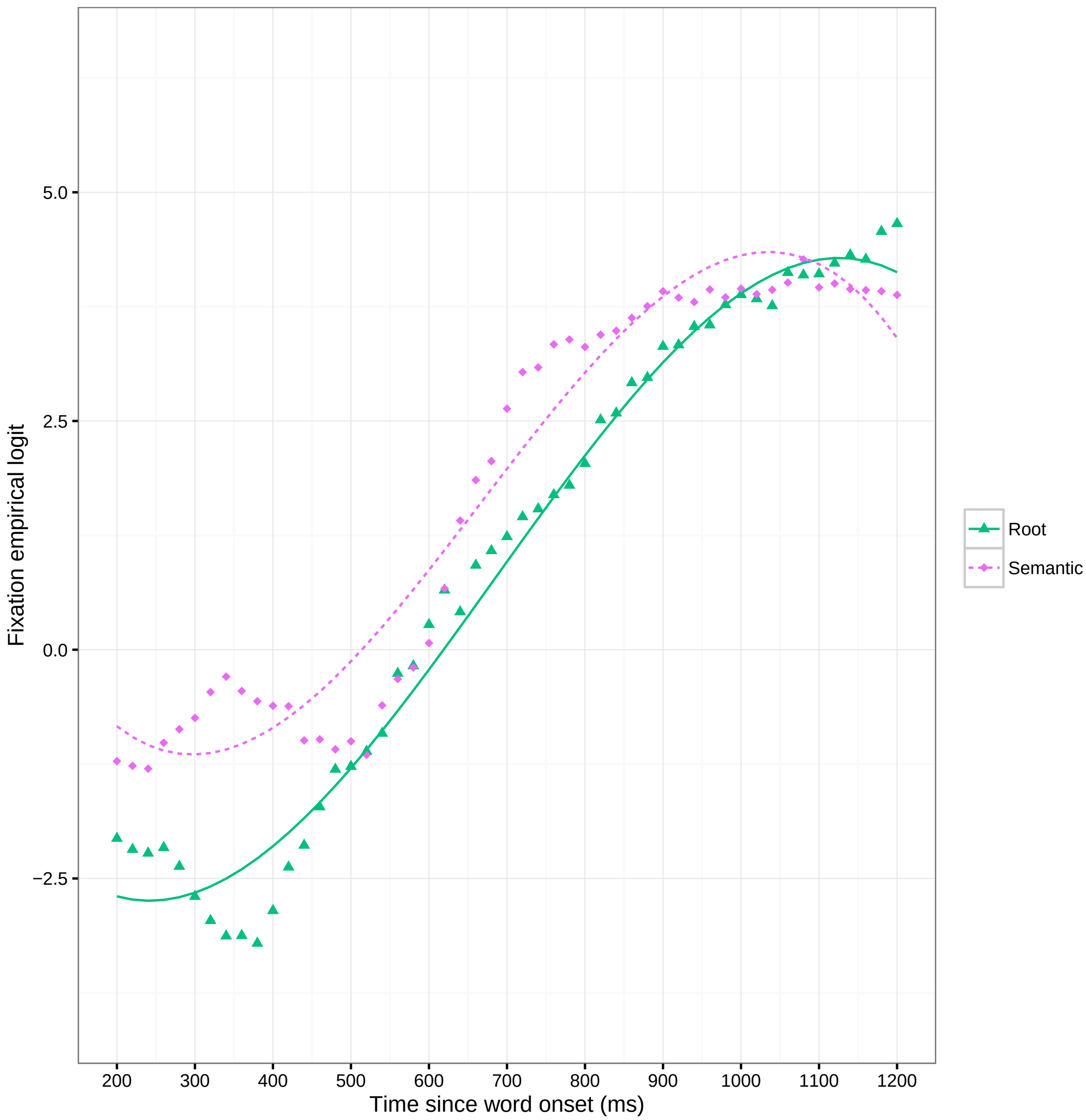

Figure 4.15: Target fixation: observed data (symbols) and GCA model fits (lines) for Root versus Semantic

With regard to competitor fixation, there was no significant effect of condition on the intercept, indicating that the overall mean of fixation was relatively similar for all conditions. However, significant differences were observed in the curvature (see Figure 4.16) of the competitor fixations in the two conditions. These differences were captured by the linear and quadratic terms, indicating that the semantic competitors curve started with a drop earlier in the time course followed by a steeper rise at a later point. No significant effect was captured by the cubic term (see Table 4.16). The results were predicted as root competitors had both phonological as well as semantic overlaps with targets whereas semantic competitors had semantic (but not phonological) overlap with targets.

	Estimate	Std.Error	t-value	p-value
(Intercept)	-3.090	0.145	-21.298	0.000
Linear	-7.368	0.967	-7.621	0.000
Quadratic	-1.851	0.919	-2.014	0.044
Cubic	2.210	0.617	3.583	0.000
Condition	-0.500	0.328	-1.523	0.128
Linear:Condition	1.690	0.595	2.840	0.005
Quadratic:Condition	1.773	0.579	3.062	0.002
Cubic:Condition	0.095	0.576	0.164	0.870

Table 4.16: Competitor Fixation: Empirical Logit GCA Results for Root (the reference condition) versus Semantic

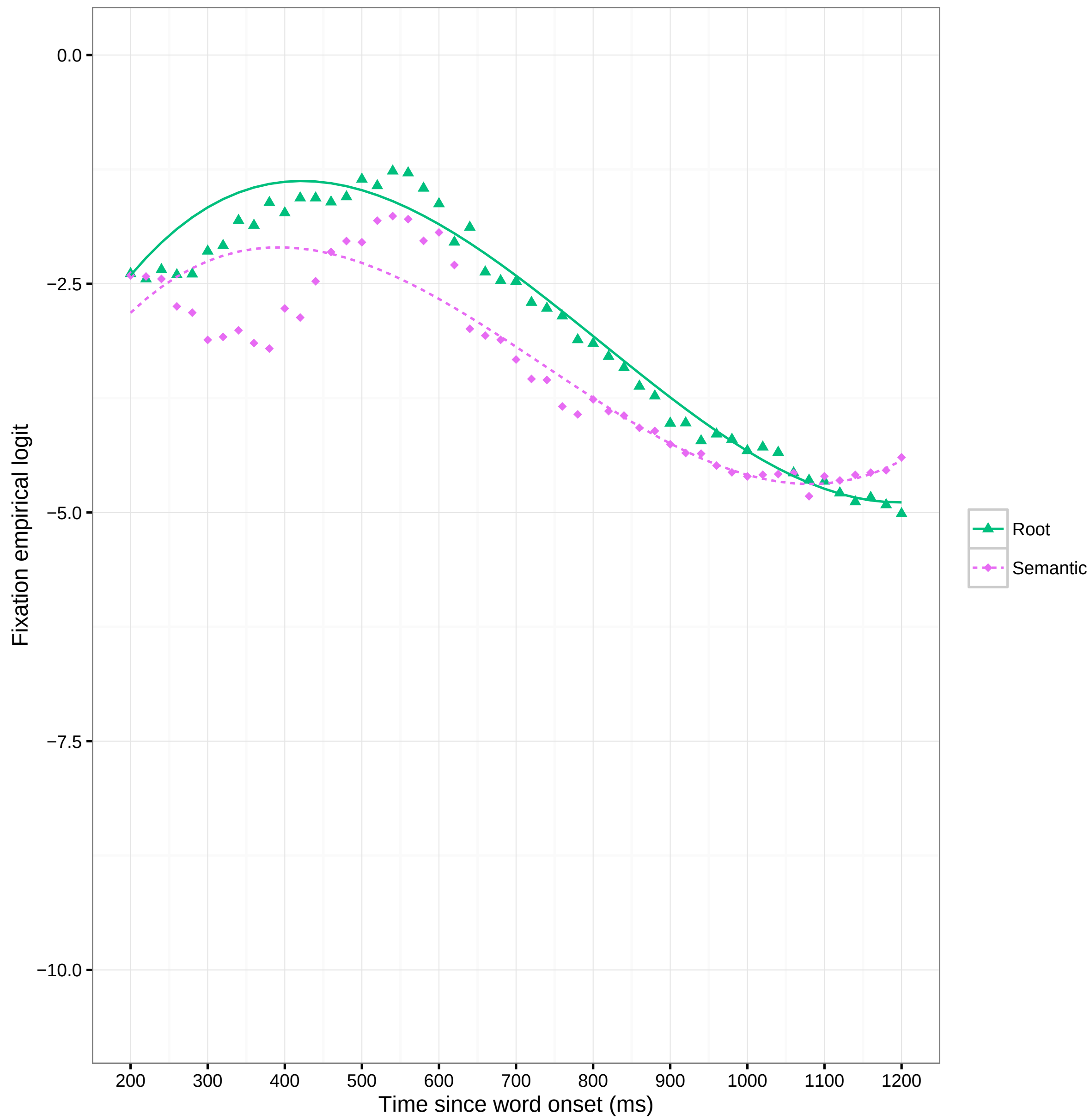

Figure 4.16: Competitor fixation: observed data (symbols) and GCA model fits (lines) for Root versus Semantic

4.3.4 Response Time Results

Data from the test trials of all the 28 participants were included; however, a number of trials were removed for various reasons. Trials in which a software error occurred were removed (11 trials: 2 baseline, 2 phonological, 3 semantic, and 4 root trials). In addition, incorrect responses were also excluded from analysis (2 trials). As well, RTs that were 2 SD from the condition mean were removed (18 trials, 9 phonological, 3 semantic and 6 root trials). So, out of 420 experimental trials, 31 trials were trimmed and 389 were subject to analysis. Table 4.17 shows mean RTs and standard deviations across conditions (also see Figure 4.17). Recall that RT was calculated by measuring the time between the onset of the spoken target word and the time at which the participant clicked on the target image (one of four images).

Trial type	Mean	St.D.
Baseline	1328.812	301.132
Phonological	1316.947	244.966
Semantic	1387.226	290.859
Root	1338.828	288.436

Table 4.17: Summary of response time means (ms) and standard deviations across trial types

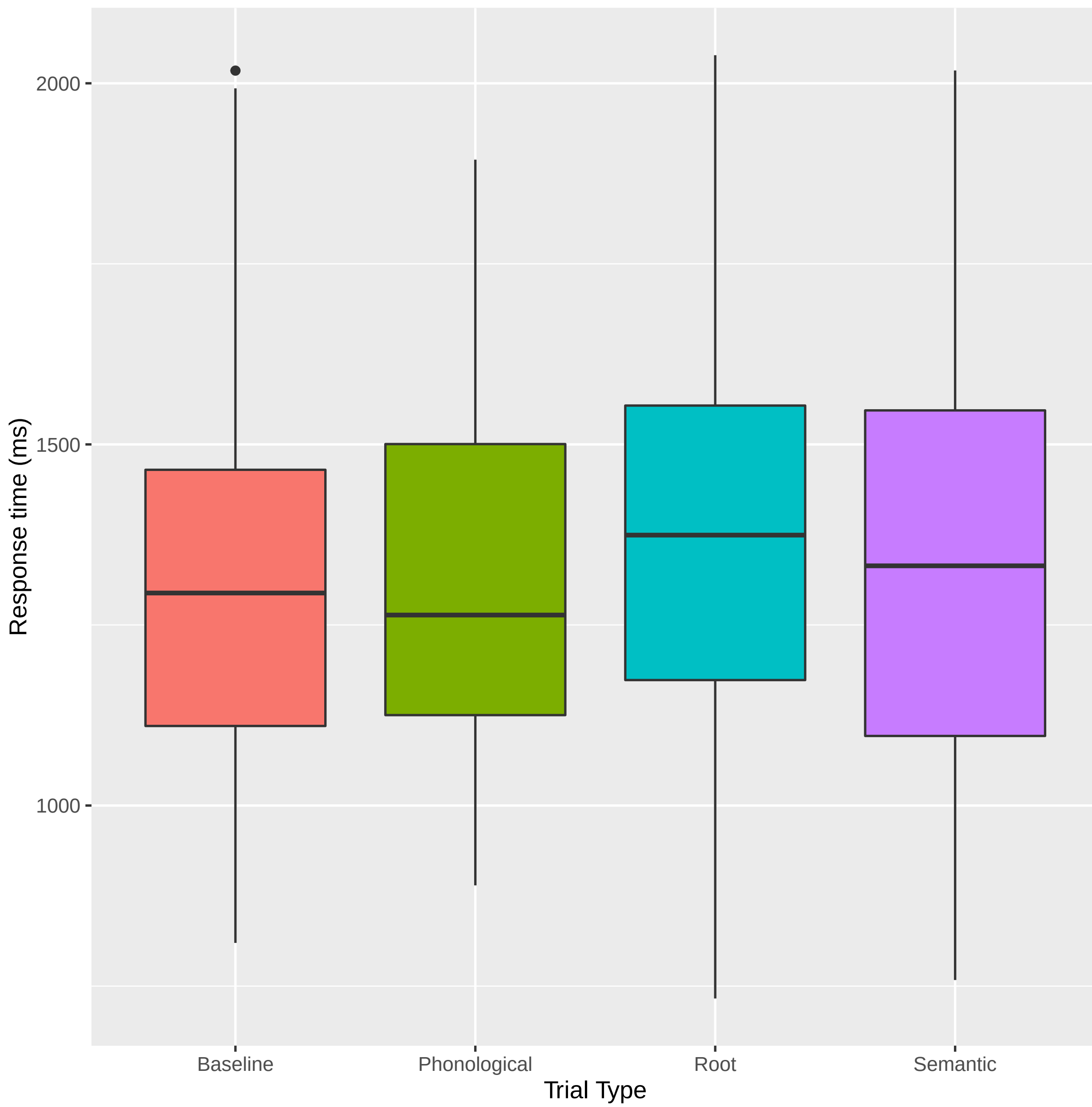

Figure 4.17: Boxplot for response times across trial types

To see if there were significant differences between these RT data in these conditions, linear mixed-effects modelling (LMEM) was used to assess the impact of trial type on reaction time. LMEM estimated both fixed effects (trial type) and random effects (participants). This model treats one of the conditions as a reference level with which to estimate parameters for each of the remaining levels. As the condition in this analysis (trial type) has four levels (i.e., baseline, phonological, semantic and root), the baseline condition was considered as the reference level for comparison (trials in which targets appeared with three unrelated distractors). This gave pair-wise comparisons for the baseline condition with each of the other conditions but not among the other levels. Results showed that there was a significant difference between RTs in the baseline condition and the root condition (see Table 4.19; $\alpha = .05$) and each of the other conditions (see Table 4.18). No significant differences were found between baseline and phonological conditions or between baseline and semantic conditions.

Since the model did not produce pair-wise comparisons between phonological, semantic and root conditions, follow up pair-wise comparisons were conducted to see if there were any significant differences in RTs between each two conditions. To do that, I used the multcomp package for R, which allowed for the conducting of multiple comparisons of the estimate coefficients $\beta$and their covariance matrix across the phonological, semantic and root conditions. Although results showed that no significant differences among experimental conditions, there was a marginally significant difference between the root and the semantic conditions.

	Estimate	Std.Error	t-value	p
(Intercept)	1328.218	39.413	33.700	0.000
Phonological	6.152	34.116	0.180	0.857
Root	67.445	33.496	2.014	0.044
Semantic	-2.014	33.423	-0.060	0.952

Table 4.18: Mixed effects analysis for response times across trial types

	Estimate	Std. Error	z-value	Pr(>|z|)
Phonological vs. Root	61.293	34.450	1.779	0.177
Phonological vs. Semantic	-8.166	34.736	-0.235	0.970
Root vs. Semantic	-69.459	33.899	-2.049	0.101

Table 4.19: Pairwise comparisons of the mixed effects analysis for response times across trial types

These results are in line with what was predicted for the root but not for the other conditions. It was predicted that RTs in all the experimental conditions would significantly differ from RTs in the baseline condition. However, only RTs in the root condition differed from the baseline condition. The presence of the root competitor caused the participants to take a longer time to click on target images than the presence of the phonological competitor. These results are also in line with the eye tracking data discussed above, in which the root competitor received the highest fixation of the types of competitors. The inhibitory effect of the root found in the present work differs from the facilitatory effect obtained from the previous priming studies on SWR in Arabic, which have found that when words were primed by root-related primes, they were recognized faster than when they were primed by phonologically or semantically-related primes (Boudelaa & Marslen-Wilson, 2000, 2015; Schluter, 2013). The different direction of effect in the present research is attributed to differences between paradigms. In the previous priming tasks by Boudelaa and Marslen-Wilson (2000, 2015); Schluter (2013), primes were presented prior to targets and hence residual activation of auditory primes facilitated target recognition. In the current research, auditory stimuli were presented while target and competitor images were visually displayed. This design forced the effect to be in an inhibitory direction as a result of the competition caused by phonological, semantic or root relatedness between targets and competitors.

4.4 Discussion

This study was conducted to investigate the phonological, semantic, and root activation in spoken word recognition in Arabic using the VWP. Adult participants were tested on their recognition of 15 Arabic words that were presented with four types of words: baseline pseudo-competitors, which were words that did not overlap phonologically, semantically or morphologically with targets; phonological competitors, which were words sharing the same onset (first 2–3 segments) with targets; semantic competitors, which were words that had semantic association with targets but no phonological overlap or morphological relatedness; and root competitors which were words sharing the same consonantal root. The results provide evidence that the VWP with eye tracking is sensitive to phonological and semantic activation, and that it is a paradigm well suited to investigating lexical activation in SWR. This confirms previous findings that have found similar graded competition for related competitors based on the amount of phonological and semantic overlaps (e.g., Apfelbaum et al., 2011; Huettig & Altmann, 2005; Huettig et al., 2006; Mirman & Magnuson, 2009; Yee & Sedivy, 2006).

With regard to the differences in fixation proportions and RTs between the baseline, phonological, semantic and root conditions, the results of this study confirmed the predictions presented at the beginning of this chapter. These predictions are presented again in Table 4.20 below for the convenience of the reader.

	Target	**Competitor**	RTs
Experimental vs. Baseline	More looks to targets in the baseline than in the phonological, semantic and root competitors due to the presence of related competitors in these conditions which is not the case in the baseline condition (✓).	Fewer looks to baseline "pseudo-competitor" than to competitors in all experimental conditions (✓).	Shorter RTs in the baseline condition than in all experimental conditions (✗).
Phonological vs. Semantic	Fewer looks to phonological targets early in the time course and more looks to the semantic target. The opposite is expected later in the time course (✓).	More looks to phonological competitors early in the time course and to semantic competitors later in the time course (✓).	RTs may not significantly differ (✓).
Phonological vs. Root	More looks to phonological targets than to root targets (✓).	Fewer looks to phonological competitors than to root competitors (✓).	Shorter RTs were also expected in the phonological condition (✓).
Root vs. Semantic	More look to semantic targets than to root targets (✓).	Fewer looks to root competitors than to semantic competitors (✓).	Shorter RTs in the semantic condition (✗).

Table 4.20: Predictions for Experiment 1 (✓and ✗indicate whether predictions were upheld or not.

GCA pair-wise comparisons of eye tracking data revealed that there were graded fixation proportions for both target and competitors that corresponded to the amount of phonological, semantic and root properties shared by targets and competitors. Target and competitor fixations in all test conditions (phonological, semantic and root) differed significantly from those of the baseline. Targets in the baseline condition were recognized faster, which was predicted due to the absence of related competitors. This was also confirmed by the shorter RTs in the baseline condition than in the other conditions (although not significantly different from phonological and semantic conditions).

When targets were presented with phonological onset competitors that shared the first 2 or 3 segments with targets (e.g., *furʃah* 'brush' / *furn* 'stove'), fixation to targets was affected and thus differed from fixation to targets in the baseline condition. Phonological competitors received high fixation early in the time course, but fixation decreased as the acoustic information from the auditory stimuli started to mismatch the representations of the phonological competitors. These results confirm previous findings from the VWP that have shown that participants are more likely to fixate on onset competitors than phonologically unrelated items (Allopenna et al., 1998; Dahan et al., 2001; Tanenhaus et al., 1995). The results provide evidence for the existence of phonological activation in SWR in Arabic that is incremental and correlated with the phonological overlap between targets and competitors. RT results showed that participants took shorter time to respond to targets in the phonological condition than in the baseline conditions.

Targets in the semantic condition were fixated more than targets in the baseline condition. The presence of semantic competitors affected fixation to targets. Observed data showed that competitor fixation in the semantic condition occurred at a later time point in the time course (at around 400 ms after word onset). This was expected as semantic access logically require some access to the phonological representation of targets before it starts. This is clear from the difference between the time course of competitor fixation in the phonological and semantic conditions, which showed that fixation to phonological competitors occurred early in the time course, whereas fixation to semantic competitors started later in the time course. These results replicate previous semantic effects that have been obtained from previous eye tracking studies (Apfelbaum et al., 2011; McMurray et al., 2003; Yee & Sedivy, 2006). RTs results showed that RTs to targets in the semantic condition versus the baseline condition were not significant. This was not expected given that targets in the semantic condition were presented with related competitors that were closely associated with them.

Targets in the root condition received the lowest fixations among all the conditions. This was explained by the examination of competitor fixations, which showed that competitors in the root condition received the highest levels of fixation compared to other conditions, indicating that the degree of competition between targets and competitors was stronger in this condition than in any other condition. These results were expected as root competitors shared both phonological and semantic properties with targets. With regard to RT data, results of the LMEM showed that there was a significant difference between RTs in the root and baseline condition. Participants responded to targets in the baseline condition significantly faster than in the root condition.

The pair-wise comparisons between phonological, semantic and root conditions in target and competitor fixations showed that the presence of root competitors caused the largest effects. RT results showed that only the root condition differed significantly from the baseline condition. No other significant differences were found. The significant differences between conditions in the fixation data versus the non-significant difference in the RT data can be attributed to the fact that eye tracking data may be able to produce more finely-grained details on the process of SWR. Also, the RT data were not from a priming study, and this methodological difference can explain why there were not as many differences in RTs between conditions.

Importantly, the fact that the presence of root competitors caused the largest effect on both target fixation proportions and RTs can be attributed to two possible reasons. First, it can be explained as evidence for the existence of morphological processing in which spoken words are decomposed. This processing level may have caused the high fixation proportions to root competitors and the delay in RTs to targets in the root condition. If this is true, the present results would provide support for previous findings that have found a priming effect of root-related primes on target recognition in both spoken and visual word recognition in Arabic (e.g., Boudelaa & Marslen-Wilson, 2000, 2001, 2004, 2005, 2015; Mahfoudhi, 2005; Qasem, 2010; Schluter, 2013), Hebrew (e.g., Deutsch et al., 1998; Frost et al., 1997) and Maltese (e.g., Ussishkin et al., 2015). They would also provide support for root and pattern theories (e.g., Bohas, 2000; McCarthy, 1981, 1986; McCarthy & Prince, 1990b) and for the models of morphological processing that allow morphological decomposition (e.g., Deutsch et al., 1998; Frost et al., 1997; Taft & Ardasinski, 2006; Taft & Kougious, 2004; Taft & Nguyen-Hoan, 2010).

Second, the effect of the root can also be attributed the fact that root competitors shared both phonological and semantic properties with targets. If this is the case, our results would provide support for interactive-activation models, which allow the interaction between form and meaning levels in SWR such as the TRACE, NAM and DCM. They would also provide support for the full-listing models of SWR (Bat-El, 1994; Benmamoun, 1999, 2003; Butterworth, 1983; Gonnerman et al., 2007; Henderson et al., 1984; Manelis & Tharp, 1977; Ratcliffe, 1997; Seidenberg & Gonnerman, 2000).

The current study cannot claim either of these possible explanations of the effect of the root obtained from this experiment. Experiment 2 was designed to investigate the effect of the root more closely by comparing root-related words with different phonological and semantic degrees of overlap. If the effect of the root is always there regardless of the semantic or phonological overlap, this would support the argument for a unitary morphological level at which the abstract representation of the root are accessed regardless of semantic transparency and phonological similarity.

Chapter 5

The Effect of the Root: Does Semantic Transparency Matter?

Semantic transparency refers the similarity in meaning between a given complex word and the source (stem or root) from which it was derived. Morphologically related words vary in the similarity of their meanings. If the meaning is clear (e.g., *casually / casualness*), the semantic relation is said to be transparent (henceforth "semantically transparent"). If the meaning is unclear (e.g., *casualty / casualness*), the relation is opaque (henceforth "semantically opaque") (Feldman & Soltano, 1999). Previous research on the effect of semantic transparency in the context of complex word recognition (mainly in the visual modality) has found controversial results. According to decompositional accounts based on studies of Indo-European languages, morphologically complex words are accessed and represented in the mental lexicon in terms of their constituent morphemes (Feldman & Soltano, 1999; Marslen-Wilson et al., 1994; Rastle, Davis, & New, 2004; Smolka, Komlosi, & Rösler, 2009). However, there is no consensus among these accounts on whether morphological decomposition is constrained by semantic transparency. Marslen-Wilson et al. (1994) conducted a series of cross-modal priming experiments to explore how English complex words are represented and accessed in the mental lexicon. They found that semantically transparent complex words (e.g., *government/govern*) are decomposed during word recognition, whereas semantically opaque complex words (e.g., *department/depart*) are not decomposed. They concluded that morphologically-complex words are represented in a decomposed manner at the level of the lexical entry, but decomposition occurs only when the meanings of the morphological relatives is transparent. Morphological relatives with opaque semantic relatedness with their constituent morphemes are accessed and represented at the level of lexical entry but in a non-decomposed manner. This conclusion by Marslen-Wilson et al. (1994) has been challenged by other studies that have found that semantic transparency is not crucial to morphological decomposition and that morphological decomposition occurs with the appearance of morphological complexity regardless of semantic transparency (e.g., Drews & Zwitserlood, 1995; Feldman & Soltano, 1999; Frost et al., 1997; Grainger, Colé, & Segui, 1991; Longtin, Segui, & Halle, 2003; Rastle, Davis, Marslen-Wilson, & Tyler, 2000; Rastle et al., 2004; Smolka et al., 2009).

According to connectionist accounts (e.g., Gonnerman et al., 2007; Kielar & Joanisse, 2010, 2011; Longtin et al., 2003; Plaut & Gonnerman, 2000; Rueckl, Mikolinski, Raveh, Miner, & Mars, 1997) morphological priming is a result of a combination of phonological similarity and semantic transparency in the system. Morphologically-complex words are represented componentially in the mental lexicon. That is words are stored separately in the mental lexicon, however, the system learns how to connect morphologically related words depending on their phonological and semantic features. The system learns the phonological (or orthographic) and semantic mapping between the surface forms of morphologically related words based on the amount of overlap between them in terms of form and meaning but not via decomposition. Therefore, morphologically-complex words that are semantically transparent can develop internal representations linked to their stems whereas morphologically-complex words that are semantically opaque develop representations different from their stems. According to these accounts, the effect of semantic transparency is graded depending on the amount of formal and semantic overlaps between morphologically related words. This view is supported by several studies that have found graded semantic transparency effects of semantically transparent, quasi-transparent and opaque morphologically related words (Gonnerman et al., 2007; Jared, Jouravlev, & Joanisse, 2016; Plaut & Gonnerman, 2000).

With regard to Semitic languages, previous research on morphological processing in both the visual and auditory modalities have found that morphological priming effects are present regardless of semantic transparency (e.g., Boudelaa & Marslen-Wilson, 2000, 2001, 2011, 2015; Deutsch et al., 1998; Frost et al., 2000, 1997; Gwilliams & Marantz, 2015; Mahfoudhi, 2005; Schluter, 2013). For instance, Boudelaa and Marslen-Wilson (2000, 2015); Schluter (2013) found that both semantically transparent and semantically opaque words produced comparable priming effects that were significantly different from the effect of phonologically related and semantically related words that were not morphologically related. These studies argue for an obligatory decompositional model of complex word recognition in Semitic languages.

The present chapter outlines the results of two experiments which were conducted to investigate the role of semantic transparency in complex word recognition among derivationally related forms in Arabic using the VWP with eyetracking. In Experiment 2A, I compared the timecourse of activation of four groups of words that differed in their relatedness to targets. These were semantically-transparent root-related words (+R+S), semantically-opaque root-related words (+R−S), phonologically-related words (but semantically and morphologically unrelated, +Phonological), and semantically associated words (but phonologically and morphologically unrelated, −R+S). These related words were compared to unrelated words that were used as a baseline condition. Targets and morphologically related words were Arabic complex words formed by vowel shifting in the word patterns and all shared the same onset. In Experiment 2B, the same design and conditions were used but with morphologically more complex targets that were formed by both vowel shifting and affixation. Targets in Experiment 2B did not share the same onsets with competitors which allowed me to examine the effect of the onset in lexical activation. These two experiments aimed to answer the following research questions:

1. Are there significant differences between the proportions of fixation to semantically transparent and semantically opaque root competitors?

2. Are there significant differences between the proportions of fixation to phonological competitors and semantically opaque competitors?

3. Are there significant differences in RTs to targets among conditions?

4. Based on the eyetracking and RT results, is the effect of the root in Arabic SWR a result of morphological decomposition or a result of interaction of phonological and semantic overlap between words?

5.1 Experiment 2A

5.1.1 Method

5.1.1.1 Participants

Participants were 35 adult native speakers of Arabic who were recruited from the Saudi Students Club in Ottawa (27 males, 8 females, mean age = 25.08, range 19-36). All participants had Arabic as their L1 and English as their L2, as determined by a language history questionnaire (see Appendix A). Despite the fact that they spoke different dialects of Saudi Arabic, the words that were used in this study were judged as familiar words by 86 Saudi individuals who were representative of all the different dialects of Saudi Arabia (see Section 5.1.1.2 below). Most participants reported that the age at which they started to learn English was 10 years or above (26 participants) except eight participants who reported learning English between the ages of 5 and 8 years. Their self-reported proficiency in English ranged from fair to very good. All participants reported that they use Arabic every day. The participants daily use of Arabic ranged from 45 to 90% with an average of 62.2% per day. All participants reported having normal or corrected-to-normal vision, normal hearing and no reading problems. All participants were compensated with CAD $10.

5.1.1.2 Stimuli

Stimuli were seven quintuplets of Saudi Arabic noun. Seven target words were selected and paired with baseline‘pseudo-competitors’ which were seven baseline words that were phonologically, semantically, and morphologically unrelated to targets. Thargets were also paired with phonological , −R+S, +R+S, and +R−S competitors. The phonological competitors (Phonological) were words that had the same root consonants with the second and third trans-positioned in most case or at least shared the first and third consonants of the root. Semantic competitors (−R+S) were words that had strong semantic associations with the target but phonologically and morphologically unrelated to targets. +R+S competitors were words that shared the same root with targets and their meanings were clearly related. +R−S were words that shared the same root with targets but their meanings were not clearly related. In addition, 14 unrelated words (divided into two groups: unrelated 1 and unrelated 2) that did not overlap semantically, phonologically or morphologically with targets were selected to be used as unrelated items. Finally, 44 words were added to be used in practice and filler trials. The majority of words were polysyllabic with the first syllable stressed (see Table 5.1). The auditory stimuli were recorded by a male native speaker of Saudi Arabic (average length = 743.57 ms, SD = 86.16; average pitch = 146.02 Hz; amplitude adjusted to be between 65 and 70dB).

Target	**+R+S**	**+R−S**	**Phonological**	**−R+S**	**Baseline**	**Unrelated 1**	**Unrelated 2**
ˈʃubbak	ˈʃabak	ˈʃabkah	ˈʃarak	ˈba:b	ˈxass	ˈqalʕah	ˈfi:l
‘window’	‘net’	‘jewelery’	‘trap’	‘door’	‘lettuce’	‘castle’	‘elephant’
	(4)	(1.44)	(1.06)	(4.21)	(1.06)	(1)	(1.40)
ˈħalla:q	ˈħali:q	ˈħilqah	ħaql	ˈdign	haˈdijjah	ˈmatˤar	ˈki:s
‘barber’	‘a shaved-beard person’	‘ring’	‘field’	‘beard’	‘gift’	‘rain’	‘bag’
	(4.8)	(1.38)	(1.02)	(4.27)	(1)	(1)	(1.19)
ˈka:tib	ˈkita:b	kaˈti:bah	ˈkila:b	ʤaˈri:dah	raˈdˤa:ʕah	ˈʤazarah	ˈmiʃratˤ
‘writer’	‘book’	‘battalion’	‘dogs’	‘newspaper’	‘nursing bottle’	‘carrot’	‘scalpel’
	(4.65)	(1.85)	(1.23)	(4.38)	(1.53)	(1.40)	(1.23)
ˈʃuħnah	ˈʃa:ħinah	ˈʃa:ħin	ˈʃaħm	ˈbari:d	ˈqird	ˈnamlah	ˈwardah
‘shipment’	‘truck’	‘shipper/charger’	‘fat’	‘mail’	‘monkey’	‘ant’	‘rose’
	(3.57)	(1.31)	(1.06)	(4.48)	(1.12)	(1)	(1.23)
ˈfarʃah	ˈfira:ʃ	faˈra:ʃah	ˈfiʃa:r	ˈkanab	ˈmu:s	ˈsamakah	ˈħa:filah
‘rug’	‘bed’	‘butterfly’	‘popcorn’	‘sofa’	‘razor’	‘fish’	‘bus’
	(4.11)	(2.55)	(1.27)	(3.74)	(1.1)	(1.08)	(1.40)
ˈʕulu:m	ˈʕa:lim	ˈʕalam	ˈʕa:mil	ˈmiʤhar	ˈhisˤ a:n	ˈna:r	ˈxaijja:tˤ
‘sciences’	‘scientist’	‘flag’	‘labourer’	‘microscope’	‘horse’	‘fire’	‘tailor’
	(4.1)	(1.44)	(1.04)	(3.70)	(1)	(1.27)	(1.29)
ˈʃurbah	ˈʃara:b	ˈʃa:rib	ʃibˈrijjah	ˈmilʕaqah	ˈtˤablah	ˈħalaq	ˈʤawwa:l
‘soup’	‘drink’	‘moustache’	‘dagger’	‘spoon’	‘drum’	‘earring’	cellphone
	(3.4)	(1.7)	(1.04)	(3.91)	(1.17)	(1.21)	(1.06)

Table 5.1: Stimuli list for Experiment 2A. Primary stress is indicated by the APA mark (ˈ) before stressed syllable. Average ratings for semantic association with targets are shown in parentheses under each word.

5.1.1.3 Familiarity ratings as a measure of word frequency

Using the same rating scale used in Experiment 1, a familiarity rating task consisting of 106 words was developed as an online survey and was sent by email to 86 individuals recruited from the Saudi Students Club in Ottawa (62 males, 24 females; mean age = 32.9; range: 19-56). The aim of this rating was to make sure that the selected stimuli were familiar to all participant and that they were present in the different spoken dialects of Saudi Arabia. None of these participants participated in the actual experiment. Familiarity ratings were analyzed by using a one-way ANOVA design with word group (8 groups: Target, Phonological, −R+S, +R+S, +R−S, and Baseline) as the between factor, and the familiarity means as the dependent variable. Results showed no significant differences among the eight word groups ($F(7, 98) = 1.67$, $p > 0.13$ (see Table 5.2). Post hoc Tukey pair-wise comparisons were used to compare familiarity rating between each two word groups to make sure that any group was significantly more familiar than the other. The p-value was adjusted to *alpha = 0.05*. This adjustment is used with multiple comparisons to limit the error rate to certain alpha level. If regular p-value were used with these multiple comparisons, the error rate would have grown with each additional comparison. Results of these comparisons demonstrated no significant differences between word groups (see Table 5.3).

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
variable	7.000	0.509	0.073	1.674	0.138
Residuals	48.000	2.084	0.043		

Table 5.2: Experiment 2A: One-way ANOVA to compare average familiarity rating across conditions

	Difference	Lower	Upper	p-adjusted
Unrelated_1 - Target	0.068	-0.285	0.421	0.999
(+R+S) - Target	-0.146	-0.499	0.207	0.890
Baseline - Target	-0.020	-0.373	0.333	1.000
(+R-S) - Target	-0.151	-0.504	0.202	0.872
Phonological - Target	-0.098	-0.451	0.255	0.987
(-R+S) - Target	0.115	-0.238	0.467	0.968
Unrelated_2 - Target	0.065	-0.288	0.418	0.999
(+R+S) - Unrelated_1	-0.214	-0.567	0.139	0.542
Baseline - Unrelated_1	-0.088	-0.441	0.265	0.993
(+R-S) - Unrelated_1	-0.219	-0.572	0.134	0.513
Phonological - Unrelated_1	-0.166	-0.519	0.187	0.808
(-R+S) - Unrelated_1	0.047	-0.306	0.399	1.000
Unrelated_2 - Unrelated_1	-0.003	-0.356	0.350	1.000
Baseline - (+R+S)	0.126	-0.227	0.479	0.946
(+R-S) - (+R+S)	-0.005	-0.358	0.348	1.000
Phonological - (+R+S)	0.048	-0.305	0.401	1.000
(-R+S) - (+R+S)	0.261	-0.092	0.614	0.293
Unrelated_2 - (+R+S)	0.211	-0.142	0.564	0.561
(+R-S) - Baseline	-0.131	-0.484	0.222	0.934
Phonological - Baseline	-0.078	-0.431	0.275	0.997
(-R+S) - Baseline	0.135	-0.218	0.487	0.926
Unrelated_2 - Baseline	0.085	-0.268	0.438	0.994
Phonological - (+R-S)	0.053	-0.300	0.406	1.000
(-R+S) - (+R-S)	0.266	-0.087	0.619	0.271
Unrelated_2 - (+R-S)	0.216	-0.137	0.569	0.532
(-R+S) - Phonological	0.213	-0.140	0.565	0.552
Unrelated_2 - Phonological	0.163	-0.190	0.516	0.823
Unrelated_2 - (-R+S)	-0.050	-0.403	0.303	1.000

Table 5.3: Experiment 2B: Pair-wise comparisons of average familiarity rating across conditions

5.1.1.4 Semantic ratings

As semantic semantic transparency is central to this experiment, a semantic rating task was conducted to rate the semantic relatedness between targets and competitors in all conditions. The rating scale was similar to the one used in Experiment 1. Forty-six participants recruited from the Saudi Students Club in Ottawa (33 males, 12 females; mean age = 31.15 years; range: 19-43 years). These participants did not participate in the familiarity rating or in the actual experiments. Semantic associations had to be strong between targets and competitors in the +R+S and −R+S conditions. They also had to be as opaque as possible between targets and the competitors in the +R−S condition. Moreover, semantic associations had to be absent between targets and competitors in the baseline, phonological and unrelated word groups. Only words that matched this criteria were included in the stimuli. Semantic transparency ratings were analyzed by using a one-way ANOVA design with word group (7 groups: Phonological, −R+S, +R+S, +R−S, and Baseline) as the between factor, and the semantic transparency means as the dependent variable. The one-way ANOVA showed a significant difference between semantic transparency means for the different word groups (see Tables 5.4). A post hoc analysis using Tukey pair-wise comparisons demonstrated significant differences that matched the required specification for the stimuli (see Tables 5.5 below). That is, the baseline, phonological, +R−S, unrelated 1, and unrelated 2 word groups were not significantly different from each other but differed significantly from targets, −R+S, and +R+S. The targets, −R+S, and +R+S did not significantly differ from each other in terms of mean semantic transparency rating.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
type	6.000	74.343	12.390	60.000	0.000
Residuals	42.000	8.673	0.207		

Table 5.4: One-way ANOVA to compare average semantic transparency rating across conditions

	Difference	Lower	Upper	p-adjusted
(+R-S) - (-R+S)	-2.618	-3.370	-1.866	0.000
(+R+S) - (-R+S)	-0.396	-1.148	0.355	0.663
Baseline - (-R+S)	-2.968	-3.720	-2.216	0.000
Phonological - (-R+S)	-3.021	-3.773	-2.270	0.000
Unrelated_1 - (-R+S)	-2.996	-3.748	-2.245	0.000
Unrelated_2 - (-R+S)	-2.900	-3.652	-2.148	0.000
(+R+S) - (+R-S)	2.221	1.470	2.973	0.000
Baseline - (+R-S)	-0.350	-1.102	0.402	0.777
Phonological - (+R-S)	-0.404	-1.155	0.348	0.644
Unrelated_1 - (+R-S)	-0.379	-1.130	0.373	0.708
Unrelated_2 - (+R-S)	-0.282	-1.034	0.470	0.904
Baseline - (+R+S)	-2.571	-3.323	-1.820	0.000
Phonological - (+R+S)	-2.625	-3.377	-1.873	0.000
Unrelated_1 - (+R+S)	-2.600	-3.352	-1.848	0.000
Unrelated_2 - (+R+S)	-2.504	-3.255	-1.752	0.000
Phonological - Baseline	-0.054	-0.805	0.698	1.000
Unrelated_1 - Baseline	-0.029	-0.780	0.723	1.000
Unrelated_2 - Baseline	0.068	-0.684	0.820	1.000
Unrelated_1 - Phonological	0.025	-0.727	0.777	1.000
Unrelated_2 - Phonological	0.121	-0.630	0.873	0.999
Unrelated_2 - Unrelated_1	0.096	-0.655	0.848	1.000

Table 5.5: Experiment 2A: Pair-wise comparisons of average semantic transparency rating across conditions.

5.1.1.5 Visual stimuli rating

The visual stimuli rating was conducted using the same procedure described in Experiment 1. All target and competitor images were presented to 5 native speakers of Arabic recruited from the Saudi Students Club who did not participate in the study. These individuals were shown the images and asked to describe each image with one word. If a participant was confused because they could describe the image with two different names, they were instructed to write the two names. The criteria was that for an image to be used, it had to be named correctly by at least 4 individuals. Images that were found to be confusing were replaced by other images and were then shown to 5 other individuals. The same procedure was repeated until all images were named correctly by at least 4 out of the 5 individuals.

5.1.1.6 Conditions

Stimuli were used to create five conditions: baseline, phonological, −R+S, +R+S, and the +R−S condition. In the baseline condition, each target image appeared with three unrelated images (recall that one of the three unrelated items was chosen to be the 'pseudo-competitor' for statistical comparisons). In the other three conditions, each target image appeared with a related competitor (phonological, −R+S, +R+S, or +R−S) and two unrelated images. The order of the trials was manually pre-randomized, and 5 ordered lists were created so that the same target was not presented twice within the same list. In each list, there were 14 test trials counterbalanced in terms of condition. The trials in each list were also randomized so that no consecutive trials were from the same condition. There were also 5 practice trials and 6 filler trials.

5.1.1.7 Procedures

All procedures were identical to the procedures described in Experiment 1.

5.1.2 Predictions

It was predicted that the phonological, −R+S, +R+S, and +R−S competitors would attract more fixations than the pseudo-competitor of the baseline condition. Therefore, targets in the baseline condition were predicted receive higher fixation than targets in all the other conditions. In addition to comparing each experimental condition with the baseline, two pair-wise comparisons relevant to the research questions in Experiment 2A were conducted. The first comparison was conducted between the two the root-related conditions (+R+S and +R−S). It was predicted that +R+S competitors would receive significantly higher fixation than +R−S competitors due to the semantic between +R+S competitors and targets which is not the case for +R−S competitors.

In the second comparison, fixations to competitors in the phonological condition are compared to those in the +R−S. There was no significant difference between the competitors in these two conditions in terms of semantic ratings with targets. The overall phonological overlap was also matched. The only difference between competitors in the phonological and +R−S conditions was that the +R−S competitors were also morphologically root-related to the targets. Therefore, if results show significantly higher fixations to competitors in the +R−S, then this strong effect could be attributed to some morphological processing during SWR in Arabic. However, if results show no significant difference, then this would suggest that any potential difference between the two root conditions in the first comparison (+R+S vs. +R−S) would be due to semantic transparency and not morphological processing.

With regard to RT data, it was expected that participants would take longer to respond to targets in all experimental conditions relative to the baseline condition as in Experiment 1. Moreover, it was predicted that RTs in the +R−S condition would be shorter than in the +R+S condition due to the transparent semantic association between targets and competitors in the +R+S condition which was expected to increase competition. Finally, shorter RTs were also predicted in the phonological condition than in the +R−S condition because the phonological competitors were only phonologically related to targets whereas +R−S competitors were phonologically and morphologically related to targets. These predictions are presented in Table 5.6 below.

	Target	**Competitor**	RTs
Experimental vs. Baseline (fixation)	More looks to targets in the baseline than in the phonological, −R+S, +R+S, and +R−S due to the presence of related competitors in these conditions which is not the case in the baseline condition.	Fewer looks to baseline "pseudo-competitor" than to competitors in all experimental conditions.	Shorter RTs in the baseline condition than in all experimental conditions.
+R+S vs. +R−S	More looks to +R−S targets than to +R+S targets due to differences in semantic transparency.	Fewer looks to the +R−S competitors than to +R+S competitors.	Shorter RTs in the +R−S condition.
Phonological vs. +R−S	More looks to phonological targets than to +R−S targets.	Fewer looks to phonological competitors than to +R−S competitors.	Shorter RTs in the phonological condition.

Table 5.6: Predictions for Experiment 2A

5.1.3 Results

This section reports and discusses the results of the proportional eye fixation data and RT data in Experiment 2A. Similar to Experiment 1, fixation data were analyzed by looking at the amount of fixation directed to different images in each display across the trials. The RT data were analyzed by measuring the time between the onset of the spoken target and the time at which the participant clicked on the target image (one of four images).

5.1.3.1 Analyses of eyetracking data

The eyetracking data of 33 out of 35 participants were analyzed. The eyetracking data from two participants were excluded due to bad calibration. In addition, all the trials involving stimulus 4 (*ʃuħnah*) were removed as the image of its phonological competitor was a real picture because it was difficult to find an appropriate image for this word (*ʃaħm* "fat") whereas all other images in the experiment were clipart images. An inspection of looking behaviour on this trial indicated that there were more fixations directed to this competitor and hence, this item was removed from analysis. The corresponding item from all conditions was also removed from analyses. The procedures used in this experiment were identical to Experiment 1. Figure 4.2 shows the average proportions of fixation to targets, competitors, and unrelated items for all conditions. The time window that was subject to GCA analyses was between 200 and 1200 ms after word onset. Visualizing Figures 5.2 and 5.3 show fixation proportions to targets and competitors across conditions. Looking at Figure 5.3, we can observe graded competition effects of the related competitors across the conditions. Similar to Experiment 1, a quasi-logistic GCA (Mirman, 2014; Mirman et al., 2008) was also used to analyze the differences in target and competitor fixations across conditions.

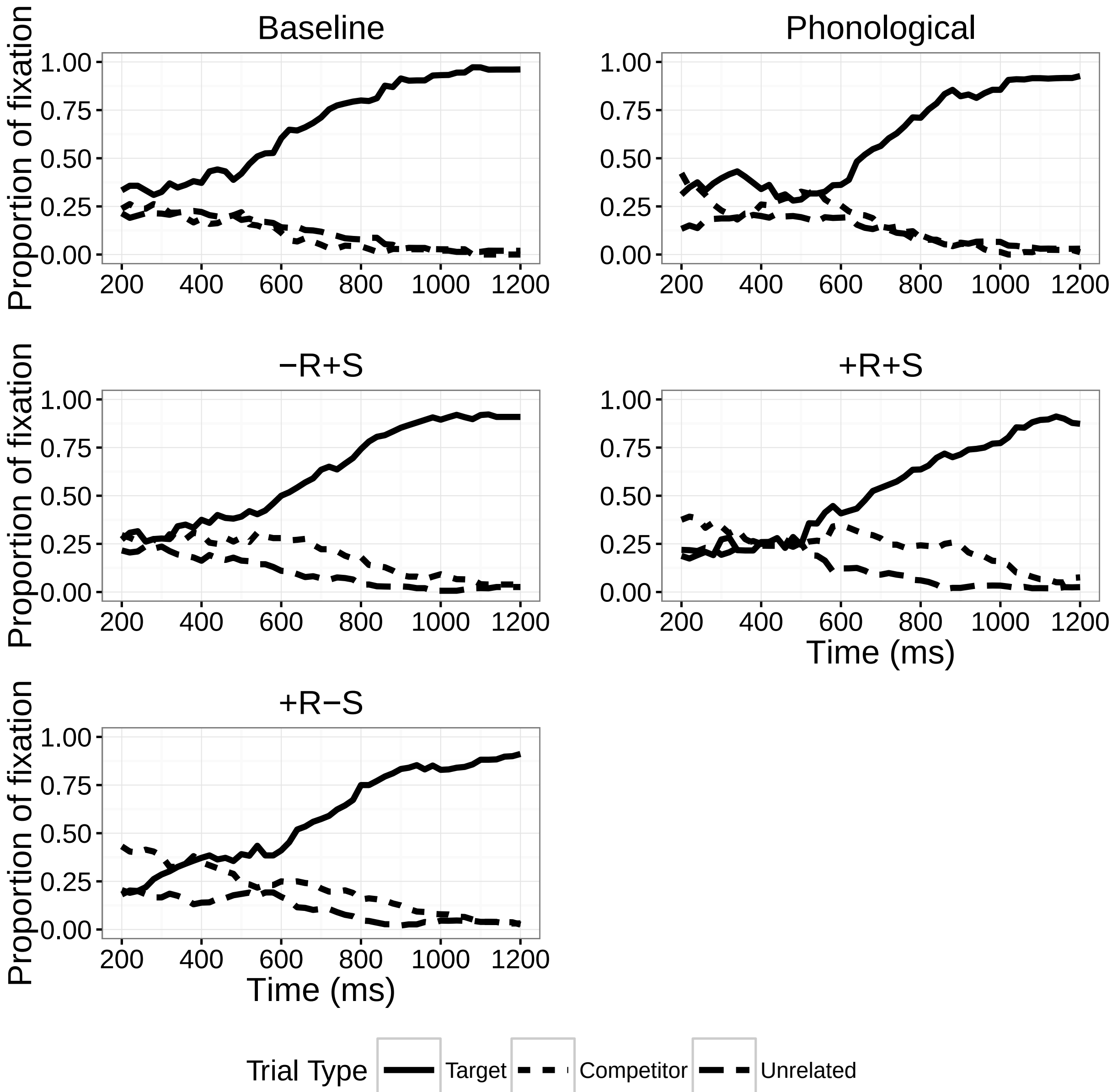

Figure 5.1: Fixation to targets, competitors, and unrelated for all conditions

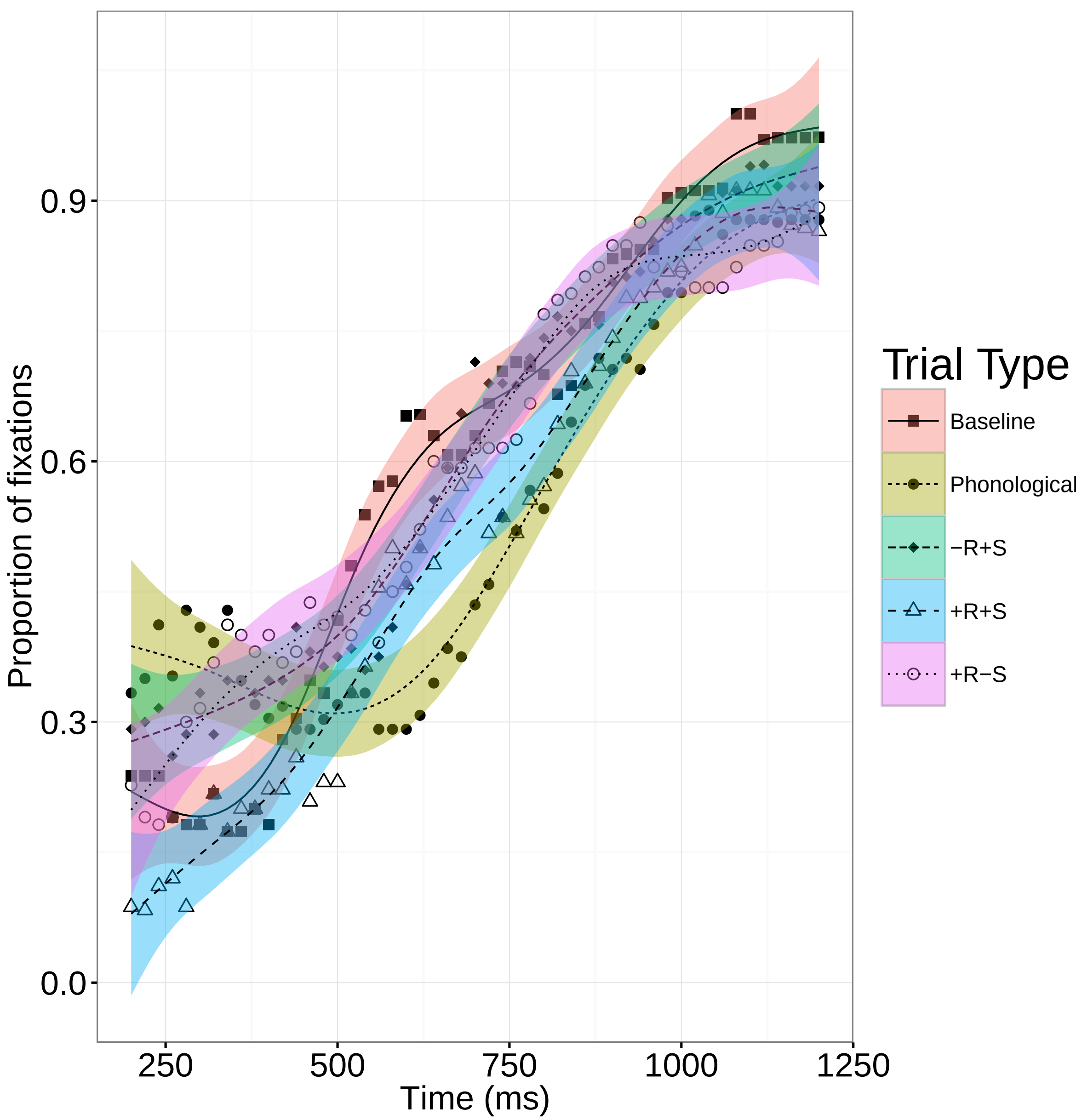

Figure 5.2: Target fixations for all conditions (LOESS smoothed lines were fit to the data)

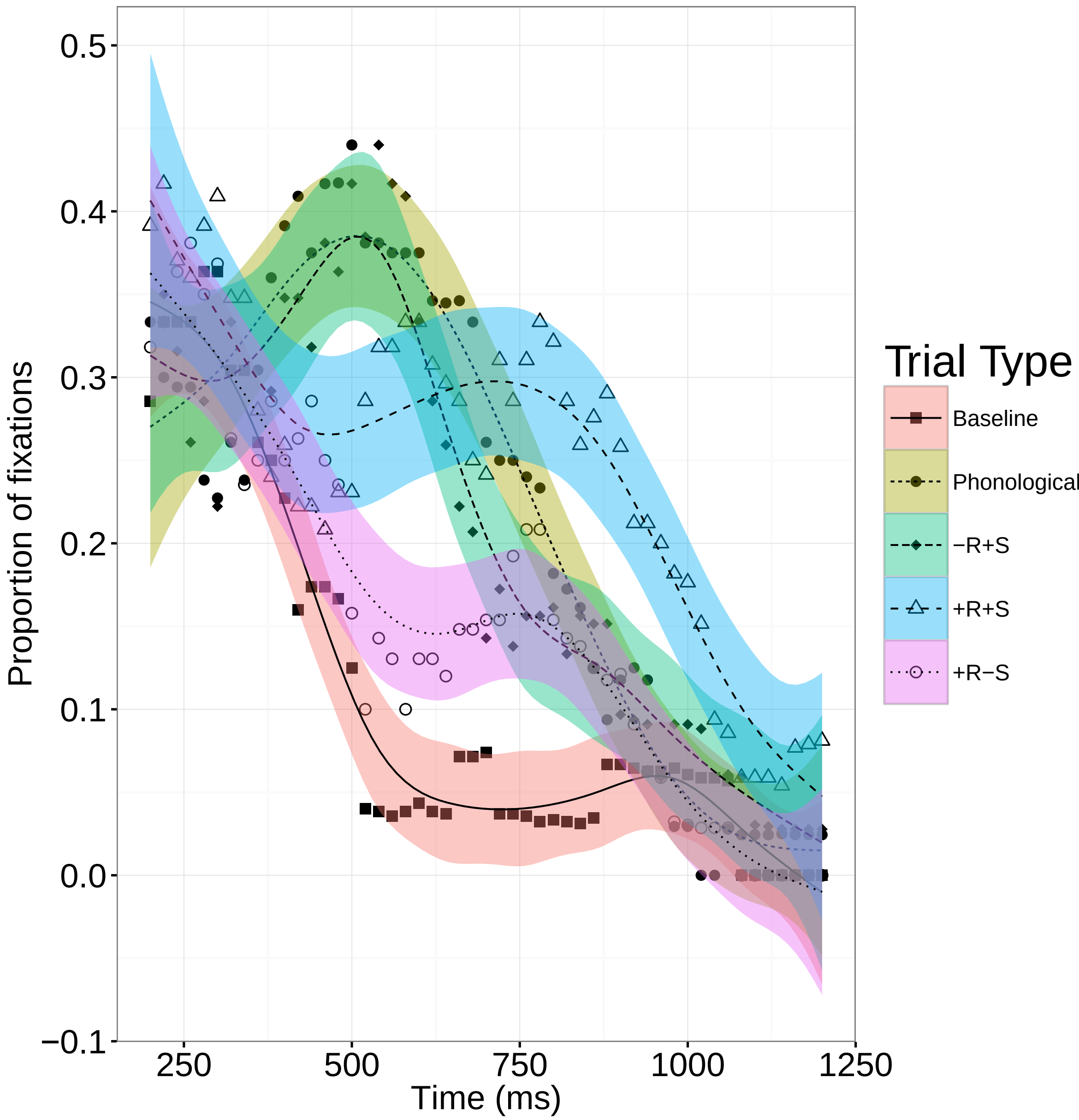

Figure 5.3: Competitor fixations for all conditions (LOESS smoothed lines were fit to the data)

5.1.3.2 Target and Competitor Fixations of experimental conditions versus baseline condition

This section describes target and competitor fixations in each of the four experimental conditions (phonological, −R+S, +R+S, and +R−S) relative to the baseline condition. In all comparisons, baseline is always treated as the reference condition.

5.1.3.2.1 Phonological versus baseline

The comparison of target fixation proportions in the phonological and baseline conditions demonstrated that there was no significant effect of condition on the intercept (see Table 5.7) indicating that the overall mean of fixation proportions was similar in the two conditions. However, the comparison revealed a significant difference between the conditions on the linear term. The fixation slope in the phonological condition was less steep than in the baseline condition (see Figure 5.4) indicating a relatively faster rate of change in fixating targets in the baseline condition. This suggests that there was an inhibitory effect on looking to the target caused by the presence of phonological competitors in the phonological condition. No other significant differences were found between the two conditions.

	Estimate	Std. Error	t-value	p-value
(Intercept)	0.282	0.543	0.519	0.604
Linear	19.302	2.445	7.894	0.000
Quadratic	2.239	2.306	0.971	0.332
Cubic	-1.992	1.213	-1.642	0.101
Condition	0.413	0.636	0.649	0.516
Linear:Condition	-5.962	1.158	-5.147	0.000
Quadratic:Condition	1.489	1.108	1.344	0.179
Cubic:Condition	-1.305	1.008	-1.295	0.195

Table 5.7: Target fixation: empirical logit GCA results for Baseline (the reference condition) versus Phonological

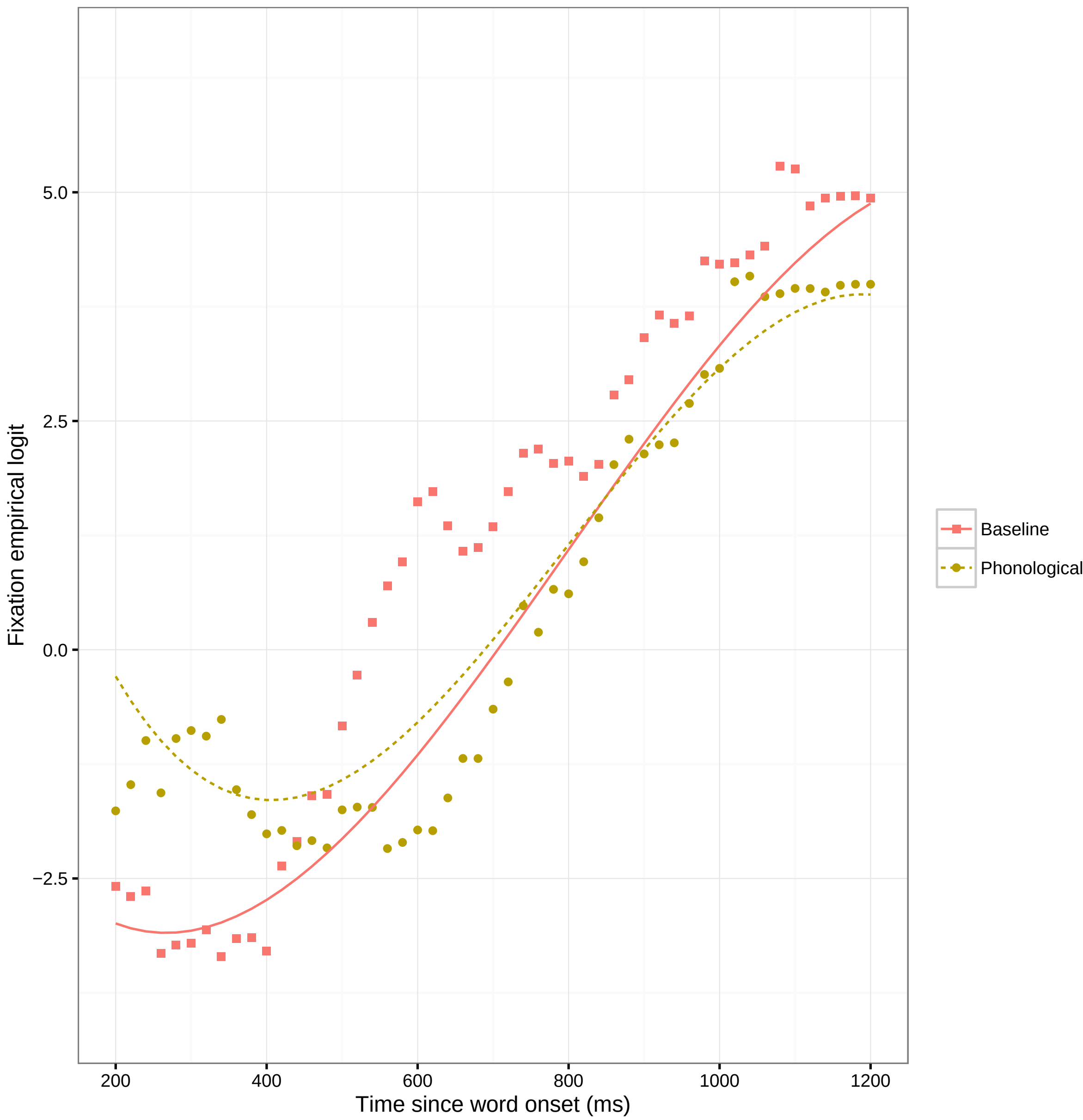

Figure 5.4: Target fixation: observed data (symbols) and GCA model fits (lines) for Baseline versus Phonological

For competitor fixation, GCA results showed that there was significant effect of condition on the intercept (see Table 5.8). The overall mean of fixations to the phonological competitors was significantly higher the overall mean of fixation to the baseline competitors. Moreover, there were significant differences between the phonological and baseline conditions captured by the quadratic and cubic terms. Figure 5.5shows a steeper downward slope for the baseline competitors' curve which reflects the difference on the linear terms (the overall angle of the curve). The downward inverted-U-shaped parabolic fixation curve for phonological competitors reflects the effect captured by the quadratic terms. The difference on the cubic term indicates more inflections in the phonological curve. These differences indicate that phonological competitors were fixated more than the baseline pseudo-competitors.

	Estimate	Std. Error	t-value	p-value
(Intercept)	-4.003	0.269	-14.891	0.000
Linear	-6.739	1.762	-3.823	0.000
Quadratic	3.841	2.056	1.868	0.062
Cubic	-3.129	1.432	-2.185	0.029
Condition	0.861	0.315	2.733	0.006
Linear:Condition	-0.640	0.942	-0.679	0.497
Quadratic:Condition	-8.262	0.920	-8.977	0.000
Cubic:Condition	7.077	0.892	7.930	0.000

Table 5.8: Competitor fixation: Empirical logit GCA results for Baseline (the reference condition) versus Phonological

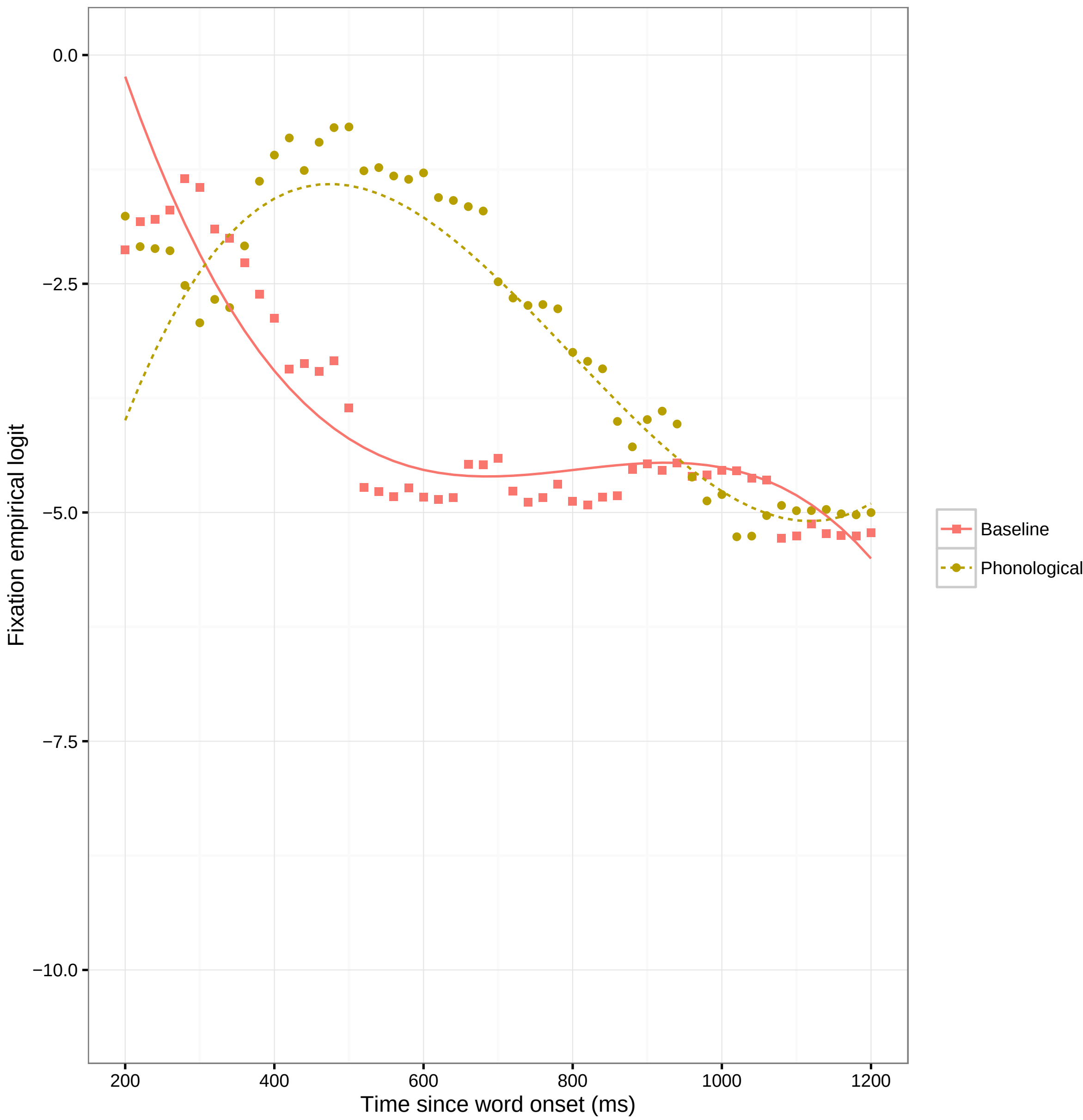

Figure 5.5: Competitor fixation: observed data (symbols) and GCA model fits (lines) for Baseline versus Phonological

These results are in line with what was predicted. Fixation to targets in the phonological condition were affected by the presence of phonological competitors compared to fixation to targets in the baseline condition. When hearing the target *farʃah* "rug", the phonologically related competitor *fiʃa:r* "popcorn" received more fixation than the baseline unrelated pseudo-competitor *samakah* “fish”. The fixation to phonological competitors mirrored the acoustic overlap between the auditory stimuli of targets and phonological competitors. This high activation of the phonological competitors reflects the overall phonological overlap between targets and competitors. Recall that in Experiment 1, the overlap was limited to the onset position and this is why there was higher fixation to phonological competitors early in the timecourse but not after 500 ms. after word onset. In this experiment, the amount of overlap between target and phonological competitors was increased so that phonological competitors shared all or at least two of root consonants of targets but in a different order. This increase in the overall overlap resulted in longer and more persistent activation of phonological competitors provide support for previous findings that have concluded that the general increase in phonological similarity between words results in an increase priming effect (e.e. Gonnerman et al., 2007).

5.1.3.2.2 −R+S versus Baseline

Comparing target fixations in the baseline and −R+S conditions showed that there was no significant effect of condition on the intercept which means that there was no significant differences between the overall proportions of fixations to targets (see Table 5.9). Surprisingly, fixation to targets in the −R+S condition was higher than to targets in the baseline condition and this is why we can see the −R+S condition slope is higher than the baseline condition slope throughout the timecourse of the trial (see Figure 5.6). Although the difference is not significant, this result was not predicted as the presence of −R+S competitors was expected to affect fixation to targets. However, the differences captured by the linear, quadratic and cubic terms showed the effects of the presence of −R+S competitors. The fixation slope of the baseline condition was steeper than that of the −R+S condition indicating faster rate of fixation to targets in the baseline condition. The difference on the quadratic term was reflected in a shallower slope downward U-shape curve for the −R+S condition indicating an increase followed by a decrease in fixation.

This decrease was explained as an effect of the presence of −R+S competitors. Finally, the significant effect captured by the cubic term was reflected in more inflections at the tails of the slope in the −R+S condition indicating that fixation to targets was affected by the presence of −R+S competitors.

	Estimate	Std. Error	t-value	p-value
(Intercept)	0.589	0.519	1.136	0.256
Linear	19.153	1.777	10.777	0.000
Quadratic	0.564	1.767	0.319	0.750
Cubic	-0.495	1.246	-0.397	0.691
Condition	0.488	0.747	0.653	0.514
Linear:Condition	-3.248	1.134	-2.863	0.004
Quadratic:Condition	-2.357	1.070	-2.203	0.028
Cubic:Condition	-2.260	1.008	-2.242	0.025

Table 5.9: Target fixation: empirical logit GCA results for Baseline (the reference condition) versus -R+S

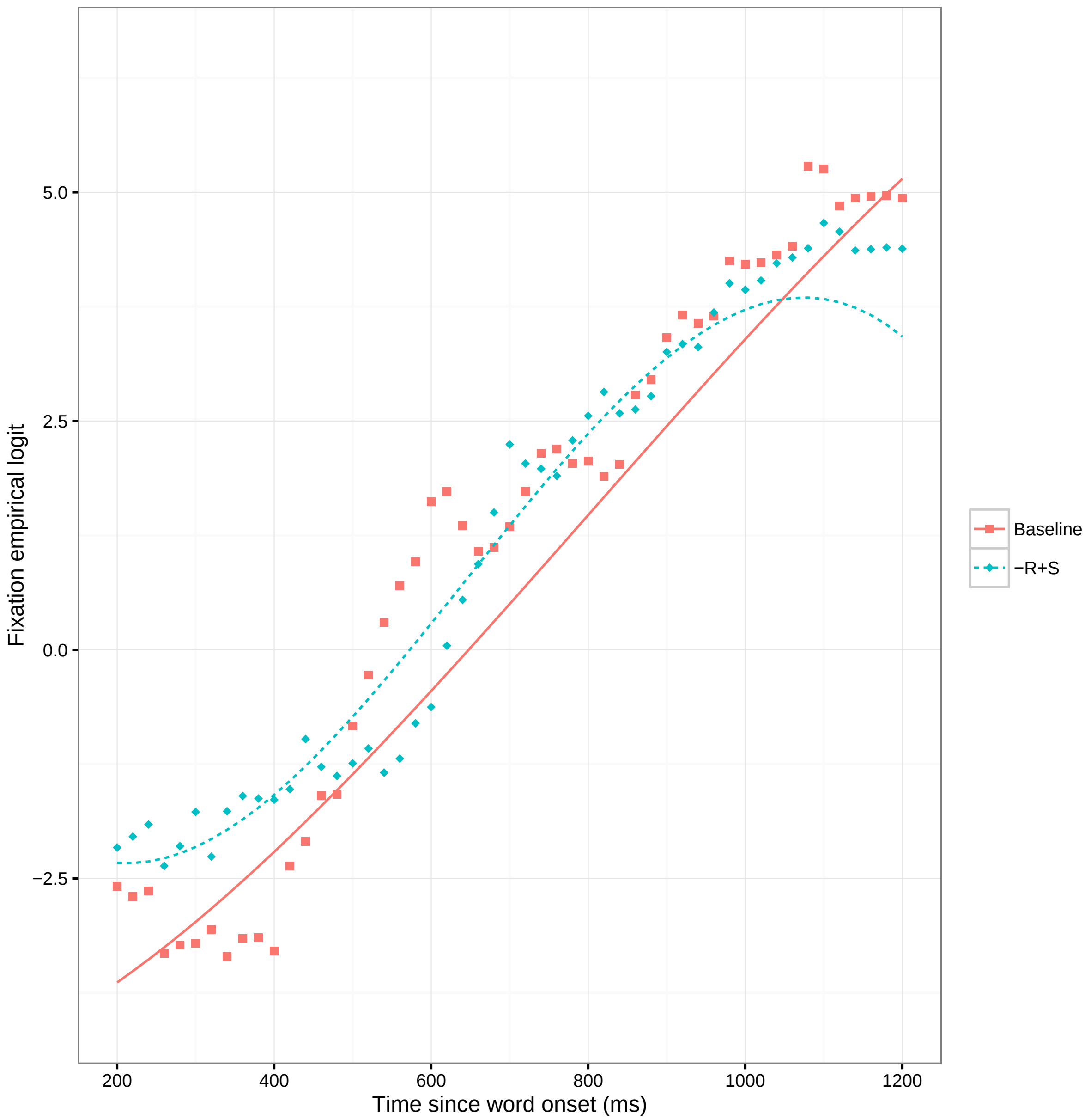

Figure 5.6: Target fixation: observed data (symbols) and GCA model fits (lines) for Baseline versus -R+S

With regard to competitor fixations, −R+S competitors received more overall looking than the baseline pseudo-competitor (see Table 5.10). Significant difference were also captured by the linear, quadratic and cubic terms (see Figure 5.7). Looking at the −R+S slope we can see that fixation to −R+S competitors started early in the timecourse and continued until around 1000 ms. after word onset.

	Estimate	Std. Error	t-value	p-value
(Intercept)	-4.329	0.287	-15.076	0.000
Linear	-3.623	2.058	-1.761	0.078
Quadratic	1.768	1.694	1.044	0.297
Cubic	-2.227	1.569	-1.420	0.156
Condition	1.303	0.458	2.845	0.004
Linear:Condition	-5.821	0.944	-6.166	0.000
Quadratic:Condition	-2.993	0.894	-3.349	0.001
Cubic:Condition	4.558	0.869	5.246	0.000

Table 5.10: Competitor fixation: Empirical logit GCA results for Baseline (the reference condition) versus -R+S

These results revealed that fixation to targets was affected by the presence of −R+S competitors. −R+S competitors were fixated more than baseline pseudo-competitors throughout the timecourse indicating the effect of semantic information in lexical access. These results are in line with previous findings on the effect of semantic association in word recognition (Apfelbaum et al., 2011; Collins & Loftus, 1975; Hutchison, 2003; Yee & Sedivy, 2006). However, these results are not in line with previous cross-modal priming studies on Arabic SWR in which prime/target pairs that had only semantic association failed to elicit significant priming effect (Boudelaa & Marslen-Wilson, 2000, 2015; Schluter, 2013). The semantic effect obtained from the current study which was not found in the previous studies on Arabic SWR suggests that the eye-tracking methodology can provide novel insights into how language is processed.

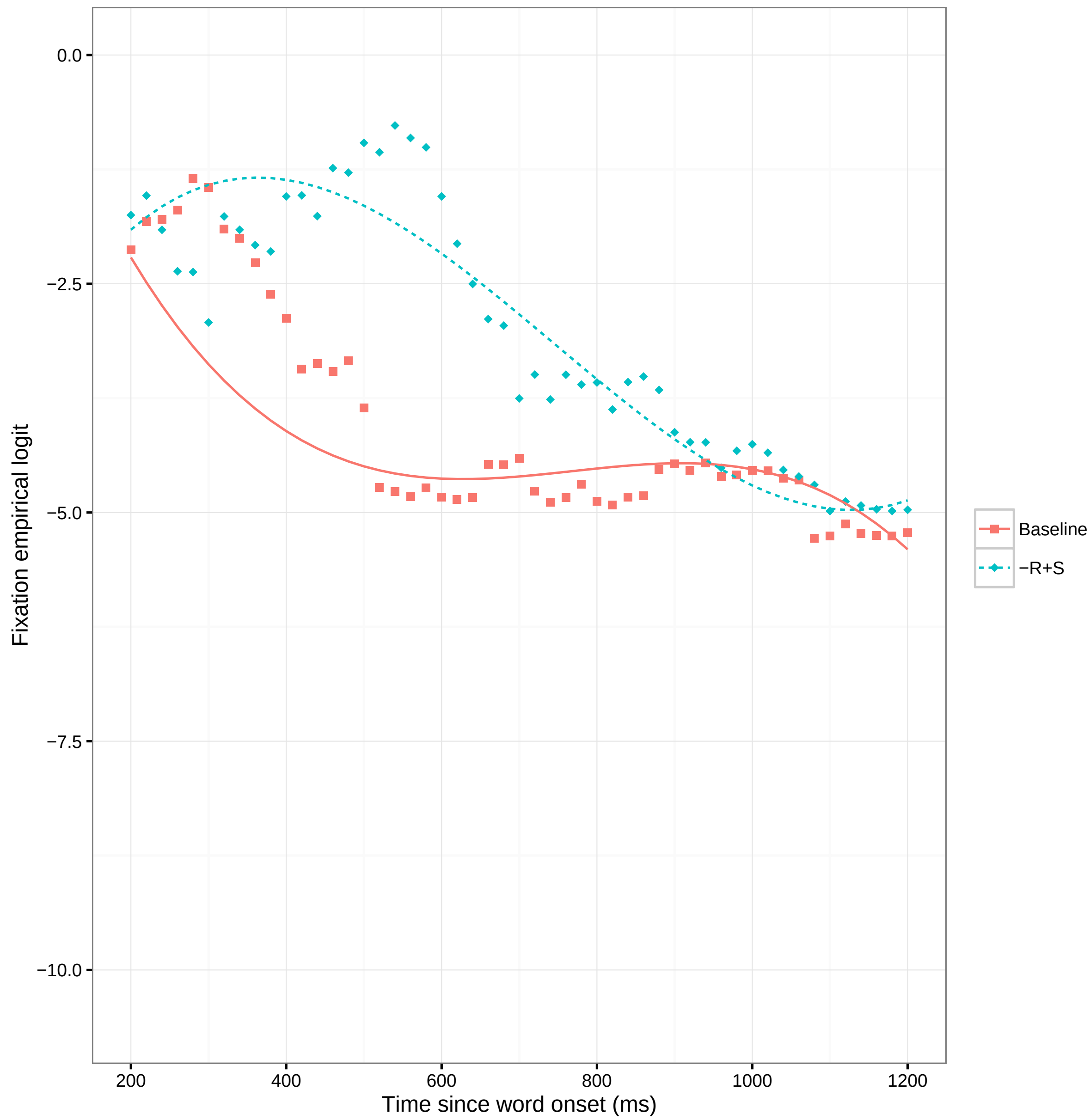

Figure 5.7: Competitor fixation: observed data (symbols) and GCA model fits (lines) for Baseline versus -R+S

5.1.3.2.3 +R+S versus Baseline

The results of comparing target fixation in the baseline and the +R+S conditions indicated that there was no significant effect of condition on the intercept (see Table 5.11) The mean of fixation to targets in the two conditions were similar. There was only a significant effect captured by the linear term. The baseline fixation curve was steeper than that of +R+S fixation curve (see Figure 5.8) indicating that target fixation was affected by the presence of +R+S competitors.

	Estimate	Std. Error	t-value	p-value
(Intercept)	0.704	0.482	1.461	0.144
Linear	19.344	1.944	9.953	0.000
Quadratic	1.351	2.199	0.615	0.539
Cubic	-2.869	1.441	-1.991	0.046
Condition	-0.873	0.679	-1.285	0.199
Linear:Condition	-2.377	0.991	-2.398	0.016
Quadratic:Condition	1.060	0.965	1.098	0.272
Cubic:Condition	1.330	0.937	1.419	0.156

Table 5.11: Target fixation: empirical logit GCA results for Baseline (the reference condition) versus +R+S

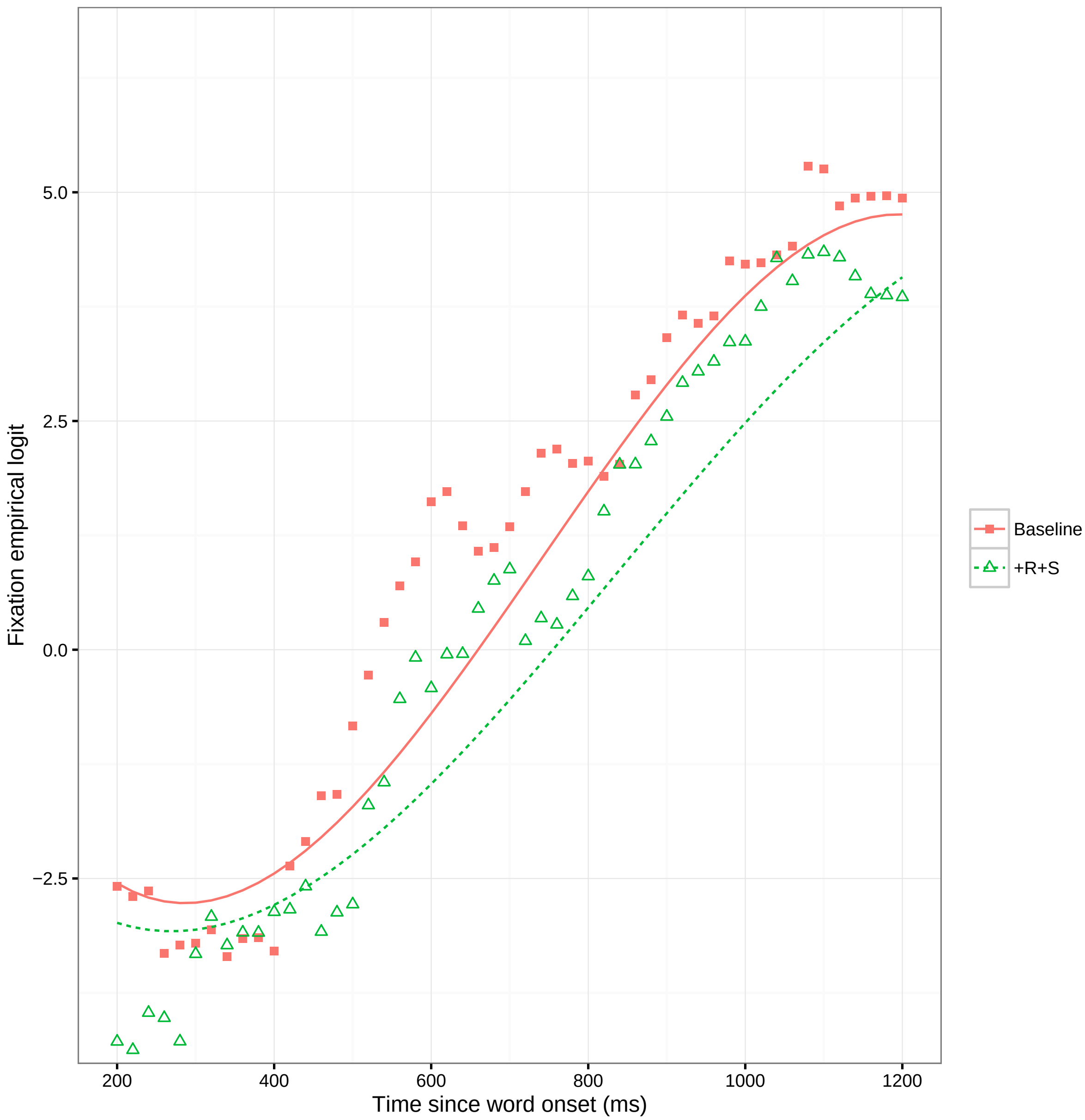

Figure 5.8: Target fixation: observed data (symbols) and GCA model fits for Baseline versus +R+S

Fixation results for competitors showed significant effects of condition on the intercept and all polynomial terms (see Table 5.12). The effect of condition on the intercept indicates that to +R+S competitors had a higher means of fixation relative to the pseudo-competitors of the baseline condition. They also had faster rate of change in fixation reflected in a less steeper (downhill) fixation curve. They had more inflections relative to the baseline condition (see Figure 5.9). All these results indicate strong activation of +R+S competitors during the SWR process.

	Estimate	Std. Error	t-value	p-value
(Intercept)	-4.095	0.234	-17.470	0.000
Linear	-6.093	2.036	-2.993	0.003
Quadratic	0.587	2.127	0.276	0.782
Cubic	-0.146	1.537	-0.095	0.924
Condition	1.965	0.641	3.064	0.002
Linear:Condition	3.931	0.822	4.780	0.000
Quadratic:Condition	-4.819	0.798	-6.037	0.000
Cubic:Condition	-2.750	0.779	-3.531	0.000

Table 5.12: Competitor fixation: Empirical logit GCA results for Baseline (the reference condition) versus +R+S

These results are in line as with what was predicted. Semantically transparent root-related words seem to receive high activation during SWR. This is in line with the results obtained from Experiment 1 of the current work. It is also in line with what has been obtained from previous research on the effect of the root in SWR (Alamri & Zamuner, 2015; Boudelaa & Marslen-Wilson, 2000, 2015; Schluter, 2013; Ussishkin et al., 2015). The large question here is whether this strong effect was driven by a morphological process involved in SWR or not. This issue is discussed later in Section 5.2.3.3.

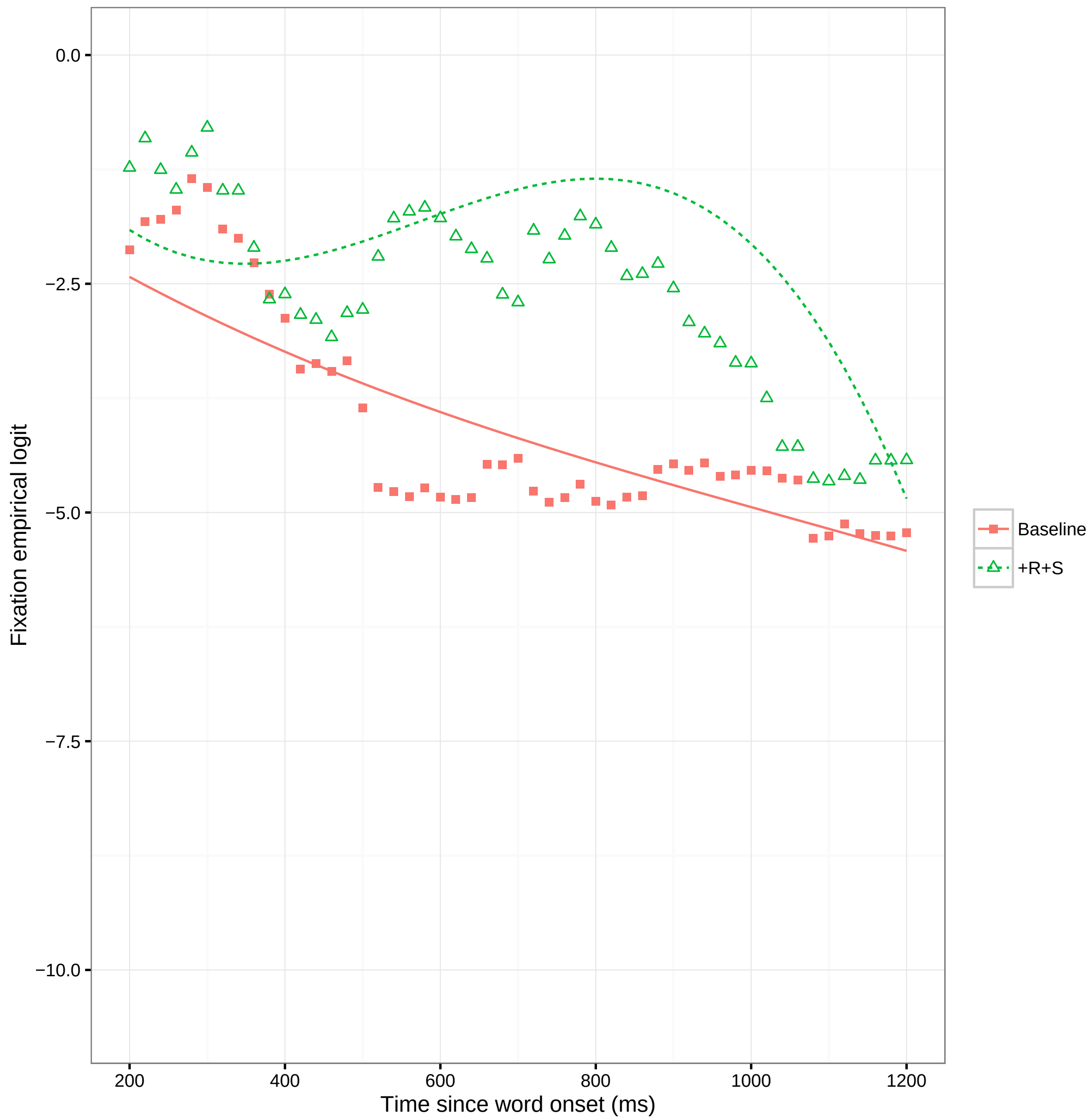

Figure 5.9: Competitor fixation: observed data (symbols) and GCA model fits for Baseline versus +R+S

5.1.3.2.4 +R−S versus Baseline

Comparing the baseline and +R−S conditions, results showed that there was no significant difference between the overall means of fixation to targets in the two conditions. There was no effect of condition on the intercept (see Table 5.13). However, there were significant differences captured by the linear, quadratic and cubic terms (see Table 5.14). These differences indicate that fixation to targets was affected by the presence of +R−S competitors (see Figure 5.10).

	Estimate	Std. Error	t-value	p-value
(Intercept)	0.680	0.431	1.577	0.115
Linear	19.472	2.216	8.788	0.000
Quadratic	-1.182	2.290	-0.516	0.606
Cubic	0.320	1.129	0.283	0.777
Condition	0.195	0.631	0.309	0.757
Linear:Condition	-5.400	1.163	-4.643	0.000
Quadratic:Condition	2.856	1.127	2.534	0.011
Cubic:Condition	-3.420	1.039	-3.293	0.001

Table 5.13: Target fixation: empirical logit GCA results for Baseline (the reference condition) versus +R-S

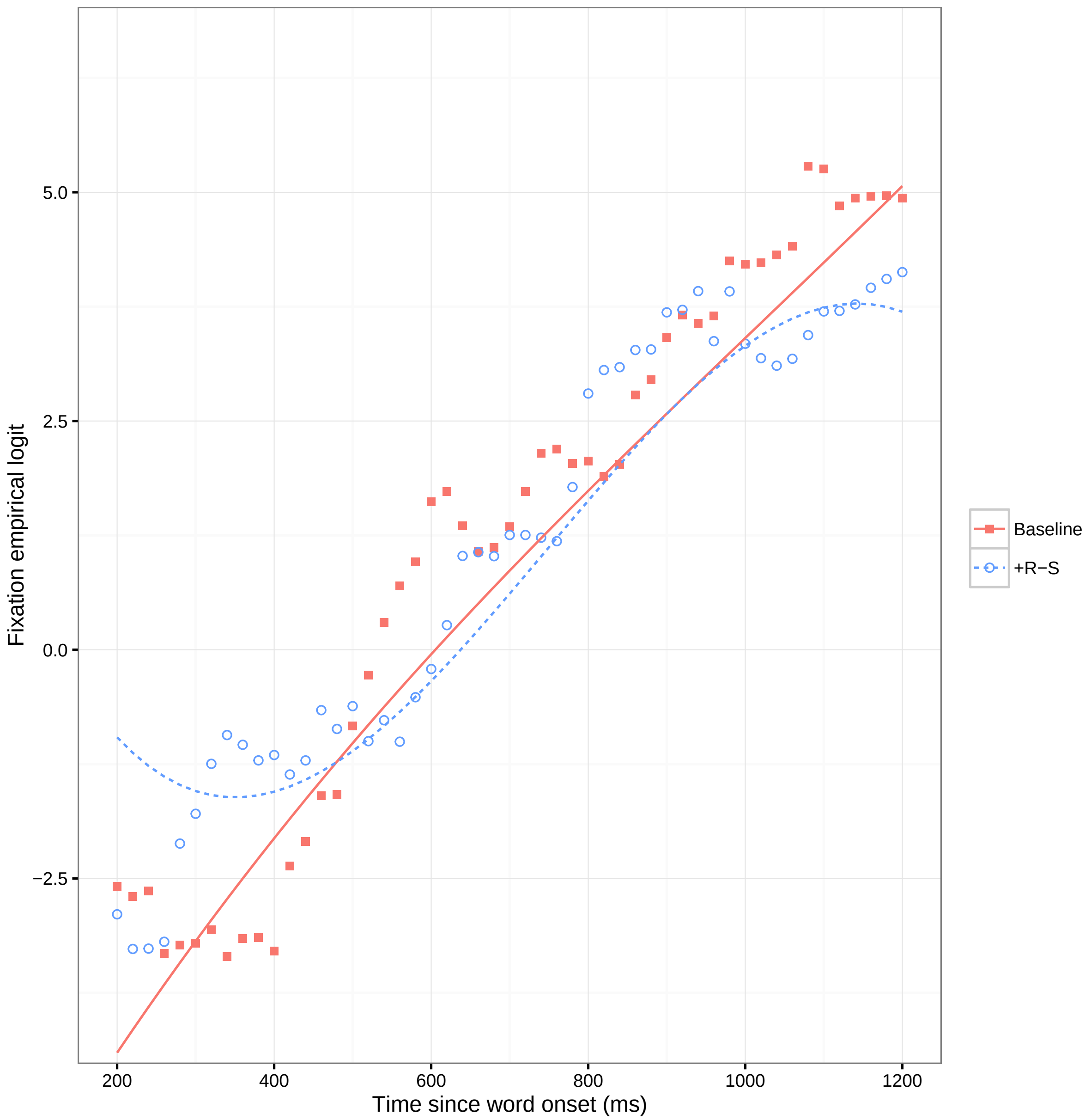

Figure 5.10: Target fixation: observed data (symbols) and GCA model fits for Baseline versus +R-S

Competitors' fixation results showed that there was no significant effect of condition which means that the overall means of fixations were similar in the two conditions. Also, there were no significant differences captured by the linear term (see Table 5.14). However, there were significant differences captured by the quadratic and cubic terms (see Figure

5.11). The difference on the quadratic term indicates more rounded downward inverted-U-shaped parabolic curve for the +R−S condition. This effect indicates that there was an increase followed by a decrease in fixation to +R−S competitors. The difference on the cubic term indicates less inflections in the curvature. These differences indicate that +R−S competitors received more activation compared to the baseline's pseudo-competitors.

	Estimate	Std. Error	t-value	p-value
(Intercept)	-3.867	0.273	-14.185	0.000
Linear	-6.952	1.890	-3.677	0.000
Quadratic	4.408	1.493	2.952	0.003
Cubic	-3.356	1.273	-2.637	0.008
Condition	0.113	0.293	0.386	0.699
Linear:Condition	-0.470	0.879	-0.534	0.593
Quadratic:Condition	-3.520	0.842	-4.179	0.000
Cubic:Condition	2.193	0.843	2.601	0.009

Table 5.14: Competitor fixation: Empirical logit GCA results for Baseline (the reference condition) versus +R-S

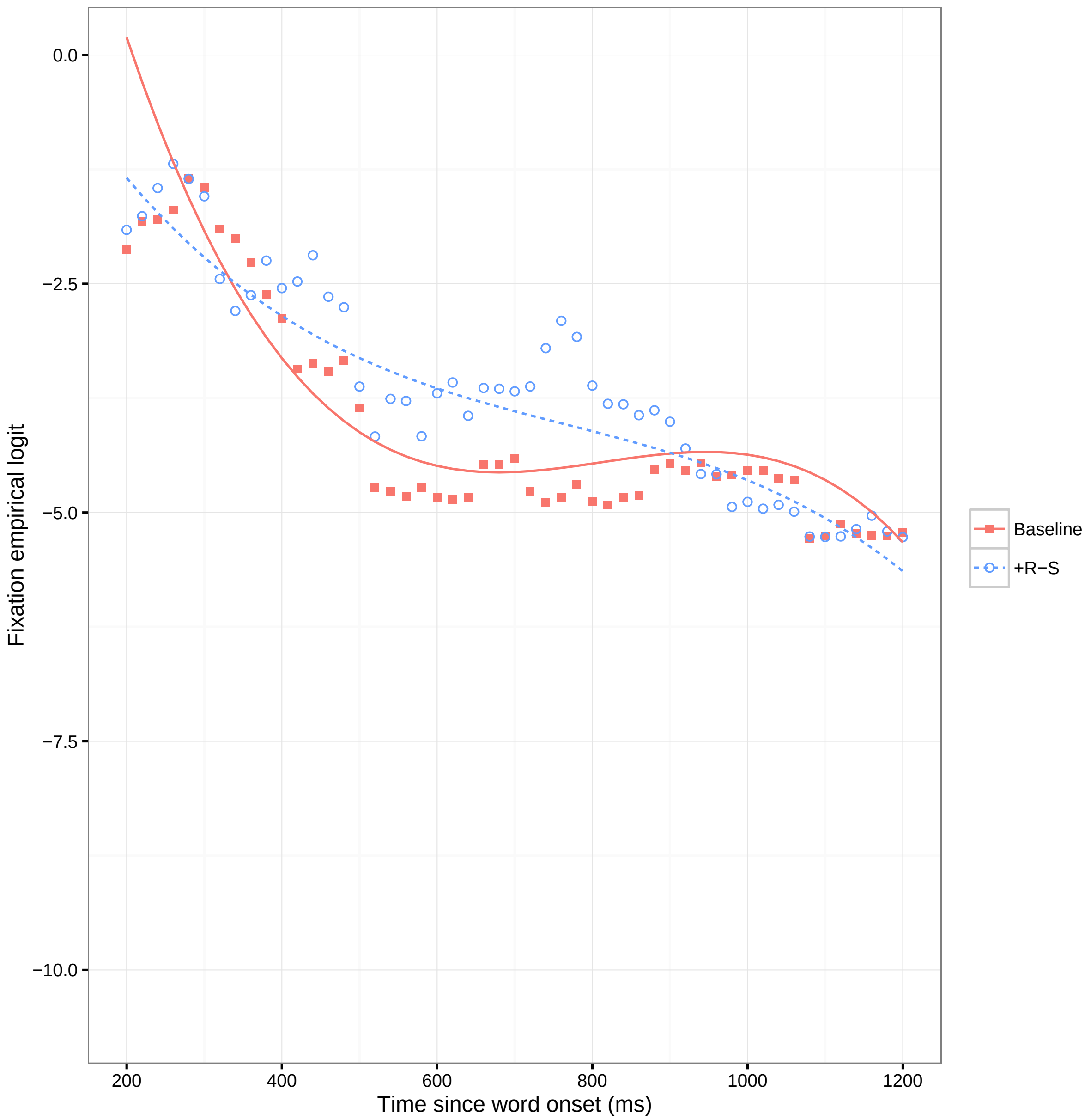

Figure 5.11: Competitor fixation: observed data (symbols) and GCA model fits for Baseline versus +R-S

These results revealed that fixation to targets in the +R−S condition was affected by the presence of semantically opaque root-related competitors, however, the effect was not as strong as the effect of the semantically transparent root-related competitors in the +R+S condition. These results are at odds with the findings obtained Boudelaa and Marslen-

Wilson (2000, 2015); Schluter (2013) which found significant priming effects of semantically opaque root related words that did not differ from those of semantically transparent root-related words (this issue will be discussed again in Section 5.2.3.3.1 and in Chapter 6). The next section will outline the results of two pair-wise comparisons that tap onto the effect of semantic transparency in SWR in Arabic.

5.1.3.3 Pairwise comparisons of competitor fixations

This section describes two pair-wise comparisons of fixations proportions: *+R+S versus +R−S* and *+R−S versus phonological* (all other pair-wise comparisons are listed in Appendix B). In these two comparisons, I only include competitor fixation results to avoid repetition and because competitor fixation results were more pronounced and informative than target fixation results.

5.1.3.3.1 +R+S versus +R−S

This analysis compares fixations to the semantically transparent root-related competitors in the +R+S (e.g., *ʃarab* 'drink') and to the semantically opaque root-related competitors in the +R−S condition (e.g., *ʃa:rib* 'moustache'). The competitors in both groups were root-related to targets (e.g., *ʃurbah* 'soup'). The results showed that there was a significant effect of condition on the intercept indicating differences in the overall means of fixation. Competitors in the +R+S condition attracted more looks than competitors in the +R−S condition. There were also significant differences captured by the linear term (see Table 5.15) indicating a higher rate of fixation to +R+S competitors.

These results highlight the role of semantic transparency in morphological activation in SWR in Arabic. They are in line with previous findings on spoken and visual word recognition in a variety of languages which have found that morphological priming is influenced by semantic transparency (e.g., Giraudo & Grainger, 2000; Gonnerman et al., 2007; Kielar &

	Estimate	Std. Error	t-value	p-value
(Intercept)	-2.184	0.528	-4.138	0.000
Linear	-5.855	1.981	-2.956	0.003
Quadratic	-2.487	2.120	-1.173	0.241
Cubic	-0.753	1.405	-0.536	0.592
Condition	-1.774	0.644	-2.755	0.006
Linear:Condition	2.019	0.957	2.110	0.035
Quadratic:Condition	0.187	0.940	0.198	0.843
Cubic:Condition	-0.671	0.904	-0.742	0.458

Table 5.15: Competitor fixation: Empirical logit GCA results for Root: +R+S (the reference condition) versus +R-S

Joanisse, 2010, 2011; Longtin et al., 2003; Marslen-Wilson et al., 1994; Plaut & Gonnerman, 2000). They are also at odds with previous findings that have argued for morphological processing that is blind to semantic information of words (e.g., Boudelaa & Marslen-Wilson, 2000, 2015; Deutsch et al., 1998; Feldman & Soltano, 1999; Frost et al., 1997; Rastle et al., 2004; Schluter, 2013; Smolka et al., 2009). With regard to Arabic SWR, the results are contradictory to the previous findings of Boudelaa and Marslen-Wilson (2000, 2015); Schluter (2013) discussed in Section 3.3 of Chapter 3. These studies have revealed that there was no significant difference between the priming effects of semantically transparent and semantically opaque root-related words. However, it is important to note that Boudelaa and Marslen-Wilson (2000, 2015); Schluter (2013) used the priming paradigm and hence the different results can be attributed to the different methodologies used in these two studies on the one hand and the current study on the other. The results of the fixation data in the current experiment found significant differences between root-related words as a function of semantic transparency. Another possible reason for the different results can be attributed to the stimuli used in Boudelaa and Marslen-Wilson (2000, 2015). In the stimuli of both Boudelaa and Marslen-Wilson (2000, 2015), some targets shared phonological onsets with +R+S competitors but not with +R−S competitors. In addition, targets and competitors were a mix of prefixed and non-prefixed complex words. Having prime/target

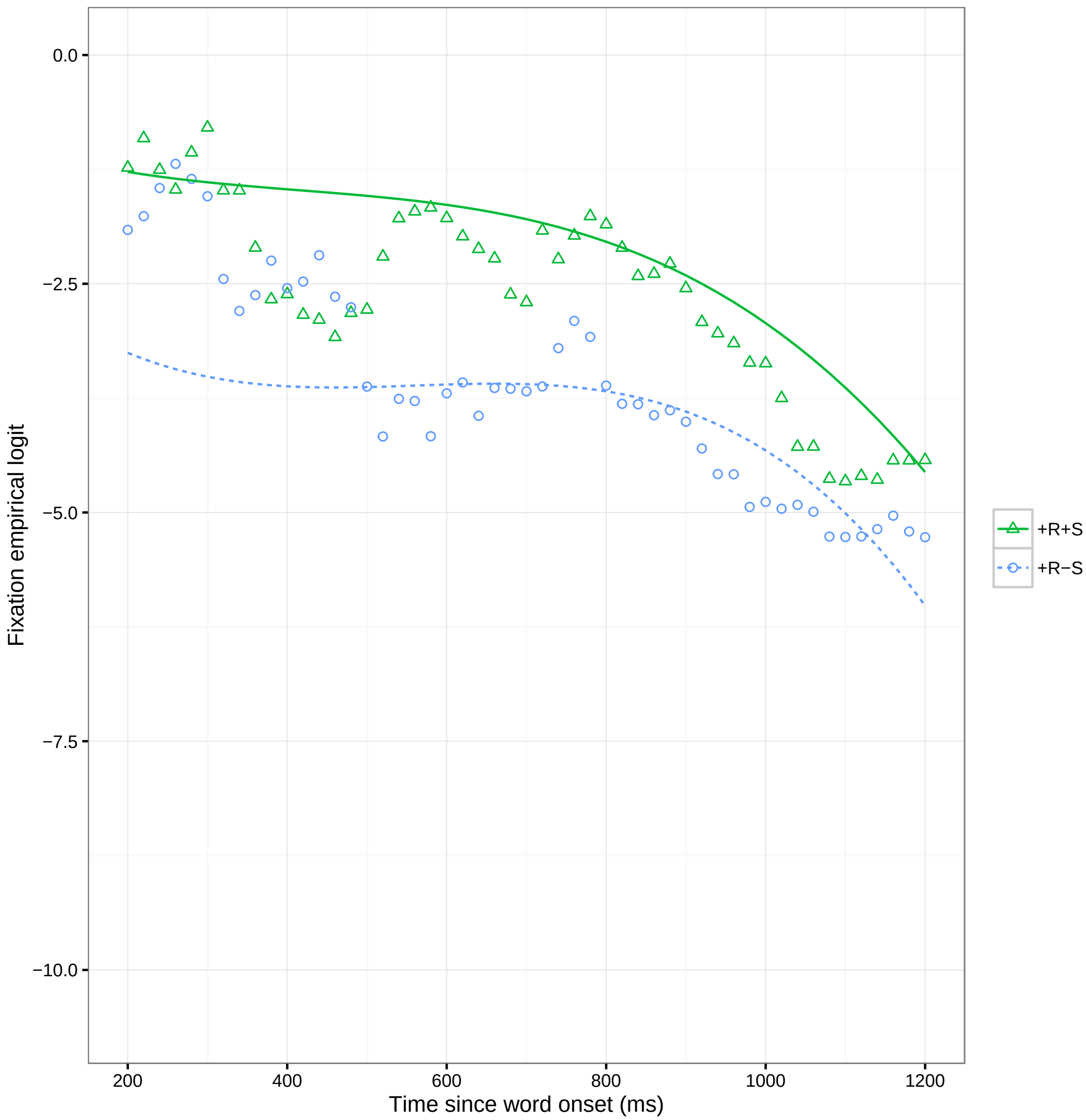

Figure 5.12: Competitor fixation: observed data (symbols) and GCA model fits for +R+S versus +R-S

pairs in which one word was prefixed and the other non-prefixed might have caused more morphological decomposition than phonological and semantic processing. In the current experiment, phonological onset was controlled for, so all +R+S and +R−S competitors shared onsets with targets. All targets and competitors were non-affixed complex words.

Prefixed complex words were analyzed separately in Section 5.2.

All in all, the results of this analysis indicates that semantic transparency plays an important role in complex word recognition in Arabic. Finally, the results of this comparison can best be accommodated by the distributed connectionist accounts that claim for graded non-decompositional processing (e.g., Gonnerman et al., 2007; Marslen-Wilson et al., 1994; Plaut & Gonnerman, 2000).

5.1.3.3.2 Phonological versus +R−S

In this section, fixations to the semantically opaque root-related competitors in the +R−S condition were compared to fixations to the phonologically but not semantically related competitors.

Recall that targets and competitors in the +R−S condition belonged to the same root and hence are morphological related. However, the semantic relatedness between targets and +R−S competitors were opaque. On the other hand, phonological competitors and targets did not belong to the same roots and hence are not morphologically related. They were also semantically unrelated to targets. So what the stimuli in the two conditions in question had in common was that they were both phonologically related to targets. The phonological competitors were created by choosing words that shared the same root consonants with the second and third consonants transposed. So, for a target such as far*ʃah* 'rug', the +R−S competitor was *fara:ʃah* 'butterfly' and the phonological competitor was *fiʃa:r*. When trans-positioning was not possible, phonological competitors shared at least the first and third consonants of the targets roots. This design enabled us to more closely match the overall phonological overlap between targets and competitors in the two conditions. In addition, semantic effects were minimized by using root-related words in the +R−S condition that had very weak semantic association with targets. Therefore, a significant difference in competitor fixation in favour of the +R−S condition would be evidence of a morphological decomposition process occurring during the process of SWR. However, if no significant differences between the two conditions were found, we can conclude that either morphological processing does not exist in SWR in Arabic or that it is mediated by semantic transparency - that is, morphological processing is limited to semantically transparent root-related words.

Comparing competitors' fixations in these two conditions revealed that there was a significant effect of condition on the intercept indicating that the overall mean of fixation to the phonological competitors was higher than the overall fixation to the semantically opaque root-related competitors in the +R−S condition (see Table 5.16). There was also a significant difference in the curvature captured by the quadratic and cubic terms. This difference is reflected in a sharper downward inverted-U-shaped parabolic fixation curve for phonological competitors which indicates a steeper increase followed decrease in fixations to phonological competitors (see Figure 5.13).

	Estimate	Std. Error	t-value	p-value
(Intercept)	-3.012	0.315	-9.558	0.000
Linear	-7.552	1.979	-3.817	0.000
Quadratic	-3.906	1.722	-2.269	0.023
Cubic	2.110	1.053	2.003	0.045
Condition	-0.864	0.276	-3.130	0.002
Linear:Condition	-0.068	1.043	-0.065	0.948
Quadratic:Condition	6.009	1.010	5.953	0.000
Cubic:Condition	-3.247	0.938	-3.461	0.001

Table 5.16: Competitor fixation: Empirical logit GCA results for Phonological (the reference condition) versus +R-S

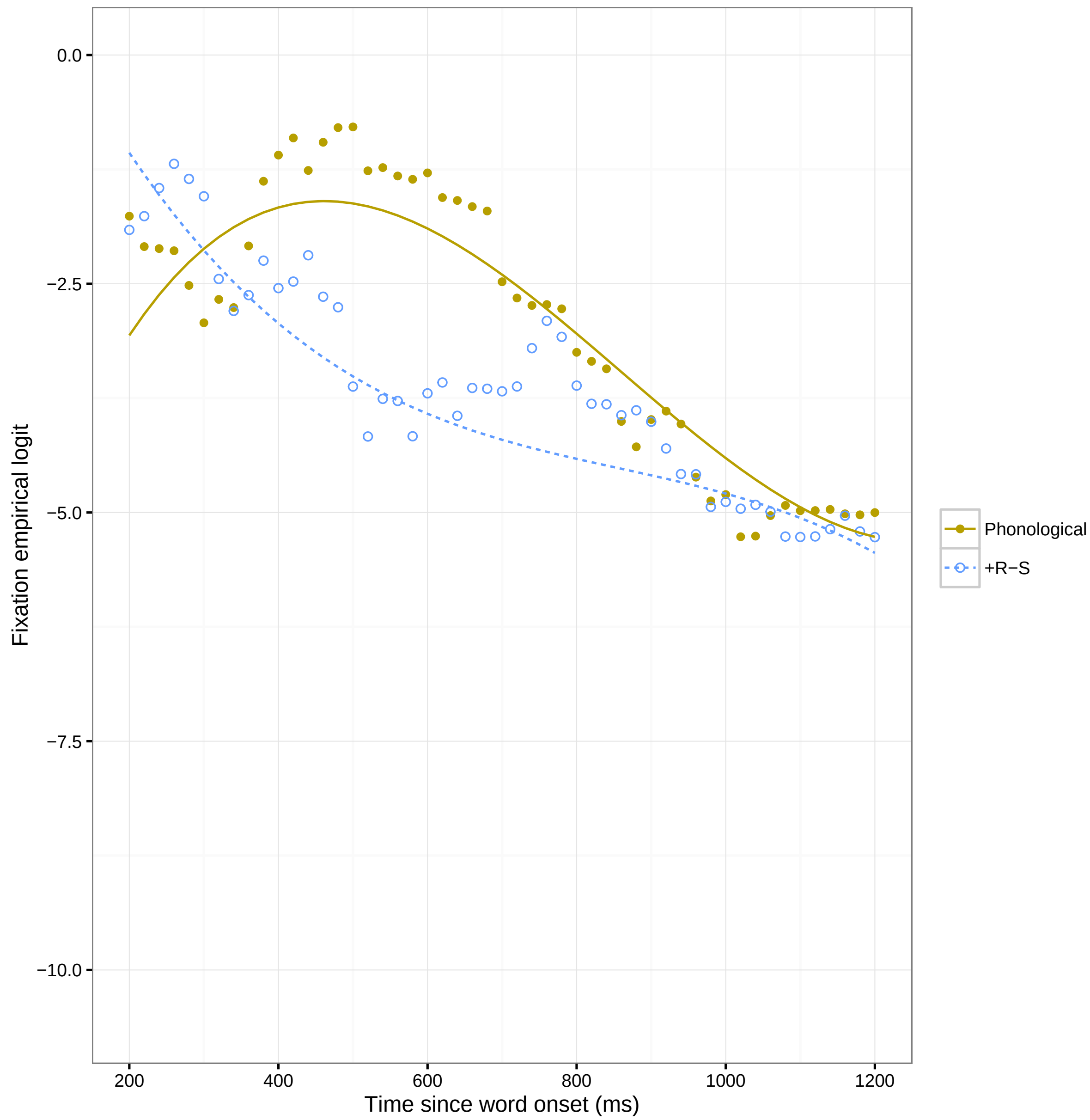

Figure 5.13: Competitor fixation: observed data (symbols) and GCA model fits for Phonological versus +R-S

The results of this comparison were surprising given that the +R−S competitors and the phonological competitors had similar amount of phonological overlap. It was predicted that the +R−S competitors would attract more or at least similar fixations. However, results revealed that phonological competitors received higher fixation than +R−S competitors.

Although it is challenging to provide a clear explanation of these results at this point, one could posit this surprising result was a result of the fact that more phonological competitors matched targets in terms of grammatical gender. Out of the six phonological competitors, four matched targets in gender. By contrast, only one +R−S competitor matched its target in gender whereas five competitors mismatched. Consequently, phonological competitors received more fixation than +R−S competitors because they had phonological similarity as well as similarity in grammatical gender. Despite the fact that attributing this unexpected finding to grammatical gender was speculative, previous research has found that grammatical gender has effects on object categorization (e.g., Cubelli, Paolieri, Lotto, & Job, 2011). Grammatical gender has also been found a source of information that can facilitate lexical access (e.g., Bentrovato, Devescovi, D'amico, & Bates, 1999; Duffy & Keir, 2004).

5.1.3.4 RT data

Data from the test trials of all 33 participants were included in the analyses of response times. The data of the two participant that were removed from the eyetracking data due to poor calibration were also removed from RTs data. Incorrect responses were also excluded from analysis (6 +R+S trials). In addition, trials in which a software error occurred were removed (11 trials: 1 baseline, 2 phonological, 4 −R+S, 2 +R+S, and 2 +R−S trials). Out of 245 experimental trials, 18 trials were trimmed and 227 were subject to analysis. Table 5.17 shows mean RTs and standard deviations across conditions. Results showed that participants took shorter time to click on target images in the baseline condition than in all the other conditions.

Trial type	Mean	St.D.
Baseline	1379.854	229.106
Phonological	1568.021	340.183
-R+S	1407.444	357.067
+R+S	1441.780	263.138
+R-S	1407.064	318.046

Table 5.17: Exp 2A: Summary of response time means and standard deviations across trial types

To see if there were significant differences between these RT data, Linear Mixed-Effects Modelling (LMEMs) was used to assess the impact of condition (trial type) on reaction time. LMEMs estimated both fixed effects (condition), and random effect (participants). LMEMs produced pair-wise comparisons for the baseline condition with each of the other conditions. Results showed that there was a significant difference between RTs in the baseline condition and the phonological condition (see Table 5.18). There were no other significant differences.

	Estimate	Std. Error	t-value	p-value
(Intercept)	1369.183	31.111	44.010	0.000
Phonological	170.191	54.088	3.147	0.002
-R+S	-39.352	41.489	-0.948	0.343
+R+S	48.451	43.938	1.103	0.270
+R-S	-17.505	51.442	-0.340	0.734

Table 5.18: Exp 2A: Linear Mixed-Effects model comparing response times across trial types (Baseline is the reference condition).

Since the model did not produce pair-wise comparisons among phonological, −R+S, +R−S, and +R+S, follow up pair-wise comparisons were conducted to see if there were any significant differences in RTs between each two conditions. Results showed that RTs in the phonological condition were significantly different from RTs in the −R+S and the +R−S conditions. No other significant differences were found (see Table 5.19).

	Estimate	Std. Error	z-value	Pr(>|z|)
Phonological vs. -R+S	-209.543	56.011	-3.741	0.001
Phonological vs. +R+S	-121.740	65.640	-1.855	0.241
Phonological vs. +R-S	-187.696	60.337	-3.111	0.010
+R+S vs. -R+S	87.803	43.459	2.020	0.175
+R-S vs. -R+S	21.847	44.491	0.491	0.960
+R+S vs. +R-S	-65.956	47.424	-1.391	0.497

Table 5.19: Exp 2A: Pairwise comparisons of the mixed effects analysis for response times across trial types

These results are not in line with what was predicted based on previous results on Arabic using the priming paradigm. It was predicted that RTs in all the experimental conditions would significantly differ from RTs in the baseline condition and that the RTs in +R+S would be the slowest among conditions due to the fact that targets and competitors in this condition were phonologically, semantically and morphologically related. With regard to the +R−S, it was predicted that RTs to targets would be slower than the baseline, phonological, and −R+S condition because targets and competitors in this condition were both phonologically and morphologically related. However, results showed that only RTs in the phonological condition differed from the baseline condition. The presence of phonological competitors sharing three or more phonemes with targets including at least two root consonants caused the participants to take longer time to click on target images than when the same target was presented with unrelated items. Also, the overlap in grammatical gender between the targets and competitors in the phonological condition might also explain why RTs in this condition were slower.

The RT results of this experiment did not show any difference in RTs between root-related conditions (+R+S and +R−S conditions) and the baseline condition indicating that they did not have any inhibitory or facilitatory effects. The RT results of the present experiment differ from the facilitatory effects obtained from the previous priming studies on SWR in Arabic which have found that words were recognized faster than when when they were primed by root-related primes than when they were primed by phonologically or semantically related primes (Boudelaa & Marslen-Wilson, 2000, 2015; Schluter, 2013). The different direction of effect in the present research may be attributed to differences between paradigms as explained earlier in Chapter 4.

5.1.4 Discussion

This experiment was conducted to investigate root activation in spoken word recognition in Arabic as a function of semantic transparency. Adult participants were tested on their recognition of seven Arabic words that were presented with five types of words: baseline pseudo-competitors which were words that did not overlap phonologically, semantically or morphologically with targets; phonological competitors which were words sharing three or more phones including the onset with targets; −R+S competitors which were words that had semantic association with targets but no phonological overlap or morphological relatedness; +R+S competitors which were words sharing the same consonantal root with targets and having transparent semantic association with targets; and +R−S which were words sharing the same consonantal root with targets but having opaque semantic association with targets. It was predicted that fixation to targets in all experimental conditions would be affected by the presence of related competitors relative to the presence of unrelated items in the baseline condition. It was also predicted that participants would look more to competitors in all experimental conditions than to the pseudo-competitors of the baseline.

With regard to the differences in target fixation proportions between the baseline, phonological, −R+S, +R+S, and +R−S conditions, GCA pair-wise comparisons of eye-tracking data showed that target and competitor fixations in all test conditions differed significantly from those of the baseline. Participants looked more to targets in the baseline condition than in the other conditions except for the −R+S condition which did not significantly differ from baseline condition in the overall means of fixation to targets but differed in the effects captured by the polynomial terms. This indicates that targets in the baseline condition were recognized faster than targets in all other conditions which was predicted due to the absence of related competitors in this condition.

As for competitor fixation, competitors in all experimental conditions received higher fixations than the pseudo-competitors of the baseline condition. When targets were presented with phonological competitors, fixations to targets differed from fixations to targets in the baseline condition. The presence of phonological competitors had a strong effect on target fixation throughout the timecourse. Recall that in Experiment 1, the effect of phonological competitor was weaker because the phonological overlap with targets was limited to the first two or three segments whereas in the present experiment, the phonological overlap was increased to include all or at least two of the root consonants of the targets. Therefore, phonological competitors in this experiment received more fixations resulting in fewer target fixations. This was confirmed by the RT data as participants took the longest time to respond to targets in the phonological condition. These results confirm previous findings from the VWP that have shown that participants are more likely to fixate phonological competitors than phonologically unrelated items (Allopenna et al., 1998; Dahan et al., 2001; Tanenhaus et al., 1995).

As for mere semantic association in the −R+S condition, results showed that there was no significant difference in the overall amount of fixation to targets in the −R+S and the baseline condition. However, significant effects were captured by the polynomial terms indicating faster rate of fixation to targets in the baseline condition than in the −R+S condition. When targets were presented with −R+S competitors that were semantically but not phonologically or morphologically related to targets (e.g., *farʃah* 'rug' / *banab* 'sofa'), participants looked at targets in the baseline condition at a faster rate than to targets in the −R+S indicating that the presence of −R+S competitors affected fixation to targets (though they did not differ in the overall amount of fixation). These results support previous semantic effects that have been obtained from previous eye-tracking studies (Apfelbaum et al., 2011; McMurray et al., 2003; Yee & Sedivy, 2006). They are also in line with the results obtained from Experiment 1.

With regard to target fixation in the root related conditions, results showed that both +R+S and +R−S competitors affected the amount of fixation to targets relative to the baseline condition. However, when these two conditions (+R+S and +R−S) were compared to each other, results also showed that fixation to +R+S competitors differed significantly from fixation to +R−S competitors. This indicates a graded activation of morphologically relatives as a function of semantic transparency. This finding supports previous findings in the literature that have come to the same conclusion (Giraudo & Grainger, 2000; Gonnerman et al., 2007; Kielar & Joanisse, 2010, 2011; Longtin et al., 2003; Marslen-Wilson et al., 1994; Plaut & Gonnerman, 2000). It was also at odds with other studies on word recognition that have argued for comparable priming of morphological relatives regardless of semantic transparency in Semitic languages (e.g., Boudelaa & Marslen-Wilson, 2000, 2001, 2011, 2015; Frost et al., 2000, 1997; Schluter, 2013) and in other languages (e.g., Feldman & Soltano, 1999; Rastle et al., 2004; Smolka et al., 2009).

The results of comparing competitor fixation in the +R−S and phonological conditions revealed higher activation for the phonological competitors despite the fact competitors in the +R−S condition were phonologically and morphologically related to targets whereas phonological competitors were phonologically but not morphologically related to targets. As explained earlier, this higher activation for phonological competitors may have been the result of the fact that more phonological competitors matched targets in grammatical gender (four out of six items) than +R−S competitors (only one item).

RT results showed that only RTs in the phonological condition differed from RTs in the baseline, −R+S and +R−S conditions. These results were not as predicted as it +R+S were predicted to show longer RTs than the phonological condition. The +R−S condition was also expected to show longer or similar RTs relative to the phonological condition. A summary fixation and RTs results for Experiments 2A is provided in Table 5.20.

A "✓ symbol indicates the results fully supported the prediction; an ✗ indicates the results did not support the prediction; and a "✓✗ indicates the results were only partially supported.

	Target	**Competitor**	RTs
Experimental vs. Baseline (fixation)	More looks to targets in the baseline than in the phonological, −R+S, +R+S, and +R−S due to the presence of related competitors in these conditions which is not the case in the baseline condition (✓✗).	Fewer looks to baseline "pseudo-competitor" than to competitors in all experimental conditions (✓).	Shorter RTs in the baseline condition than in all experimental conditions (✓).
+R+S vs. +R−S	More looks to +R−S targets than to +R+S targets due to differences in semantic transparency (✓).	Fewer looks to the +R−S competitors than to +R+S competitors.(✓).	Shorter RTs in the +R−S condition (✗).
phonological vs. +R−S	More looks to phonological targets than to +R−S targets (✗).	Fewer looks to phonological competitors than to +R−S competitors(✗).	Shorter RTs in the phonological condition (✗).

Table 5.20: Summary of fixation and RT results for Experiment 2A

All in all, these results, up to this point, do not provide support for morphological decomposition models. The current fixation results showed that fixations to +R+S competitors and +R−S competitors were significantly different across the timecourse. Competitor fixations in the +R+S was also higher than competitor fixations in the phonological and −R+S conditions. These results indicate that lexical activation depends on the amount of phonological and semantic overlap with a given spoken word. Therefore, it could be said that +R+S competitors received more fixations due the joint effects of phonological and semantic similarity to targets. The results provide support for previous findings that have argued for the role of semantic transparency in morphological processing (e.g., Giraudo & Grainger, 2000; Gonnerman et al., 2007; Kielar & Joanisse, 2010, 2011; Marslen-Wilson et al., 1994; Plaut & Gonnerman, 2000).

The results, however, are at odds with the previous results on Arabic SWR that have found comparable priming effects for +R+S and +R−S competitors (Boudelaa & Marslen-Wilson, 2000, 2015; Schluter, 2013). The different results obtained from these studies can be attributed to the stimuli used. For instance, in Experiment 3 and 4 of (Boudelaa & Marslen-Wilson, 2015), the stimuli were a mix of complex words with and without added consonants. That is, some items in the +R+S competitors shared onsets with targets while +R−S competitor did not. In other items, +R−S competitors shared onsets with targets while the +R+S competitors did not. Moreover, orthographic similarity differed from item to item. In addition, in some items, one competitor was a concrete noun while the other was more abstract. These issues might have affected the results obtained in this study. This issue will be revisited in Chapter 6.

These results can best be explained within a single-route distributed connectionist model similar to the model suggested by Gonnerman et al. (2007) in which the morphological effect is a result of joint effects computed by an interlevel hidden unit that creates connections between lexical representations based on the amount of phonological, semantic and spelling similarities. Therefore, morphologically related words are given weights that reflect the strength of connections between lexical representations in terms of sounds, meanings and spelling. Weights of combined effects such as similarity in sounds and meaning would be higher than single effects. Phonological competitors received more fixation than baseline unrelated pseudo-competitors indicating the existence of phonological activation. −R+S (mere semantic) competitors also received more fixation than baseline unrelated pseudo-competitors indicating the effect of semantic association in lexical activation. Root-related competitors (+R+S and +R−S) were fixated more than the unrelated pseudo-competitors as well. However, there were significant differences between the amount of fixations to competitors in these two conditions. +R+S competitors were fixated more than +R−S competitors indicating that morphological activation increases as a function of semantic transparency. Within such a model, this high fixation of +R+S competitors indicates that morphemic priming in SWR in Arabic is a result of the convergence of phonological and semantic relationships detected by the morphological interlivel unit. In other words, the interlevel unit computes the strengths of relationships between words in the mental lexicon based on similarities in sounds, meanings, and spellings as well as other grammatical similarities.

In the following experiment (Experiment 2B), root activation is further investigated in the context of prefixed nouns. Prefixed nouns are more complex than words formed by interleaving roots and patterns. The assumption was that morphological decomposition may be more pronounced in more complex words. Experiment 2B is identical to Experiment 2A, however, the stimuli were different. Competitors in the phonological and root-related (+R+S and +R−S) conditions did not share the same onset with targets. These competitors were chosen in order to explore the effect of the phonological onset in both phonological and morphological processing. In addition, the effect of semantic transparency was tested again in the context of prefixed nouns.

5.2 Experiment 2B

As mentioned earlier, Experiment 2B is identical to Experiment 2A except for the stimuli used. Participants, conditions, methods and procedures are identical to Experiment 2A. In this section, I will describe the stimuli of this experiment and how they differed from those in Experiment 2A. Then I will report the eyetracking and RT results. This will be followed by a discussion section to explain the results and how they can fit in the current literature on word recognition.

5.2.1 Stimuli

Stimuli were seven quintuplets of Saudi Arabic nouns. Seven target words which were complex words formed by vowel shifting and affixation were used. All the targets had the prefixes *ma, mi* or *mu*. Five types of competitors were also used, namely, baseline, phonological, −R+S, +R+S, and +R−S. Baseline 'pseudo-competitors' were seven nouns that were phonologically, semantically and morphologically unrelated to targets. Phonological competitors were seven nouns that involved the same root consonants with the second and third trans-positioned in most case or at least share the first and third consonants of the root. However, unlike in Experiment 2A, they did not share the same onsets with targets. −R+S competitors were seven nouns that had strong semantic associations with the target but were phonologically and morphologically unrelated. +R+S competitors were seven nouns that shared the same root with targets and their meanings were transparent. +R−S competitors were seven nouns that shared the same root with targets and their meanings were opaque. Similar to the phonological competitors, the +R+S and +R−S competitors did not share onsets with targets and the competitors had the same onsets and similar amounts of phonological overlap with targets. An additional 14 unrelated words (divided into two groups: unrelated 1 and unrelated 2) were selected that did not overlap semantically, phonologically or morphologically with targets (see Table 5.2.1). In addition, 44 words were added to be used in practice and filler trials. Most of the words were polysyllabic with primary stress on the first or second syllable. The auditory stimuli were recorded by a male native speaker of Saudi Arabic (average length = 711.42 ms SD = 66.44; average pitch = 141.8 Hz; amplitude adjusted to be between 65 and 70dB).

Target	**+R+S**	**+R−S**	**Phonological**	**−R+S**	**Baseline**	**Unrelated 1**	**Unrelated 2**
ˈmuħrim ‘white-dressed pilgrim’	ˈħaram ‘the holy mosque’ (4.51)	ˈħurmah ‘woman’ (1.97)	ˈħumrah ‘lipstick’ (1.06)	ˈkaʕbah ‘kaabah’ (4.38)	ˈbasˤalah ‘onion’ (1.02)	saˈfiːnah ‘ship’ (1.42)	ˈkaʃʃaːf ‘flashlight’ (1.1)
ˈmalħamah ‘meat shop’	ˈlaħam ‘meat’ (4.68)	ˈliħaːm ‘welding’ (1.46)	ˈlawah ‘board’ (1.31)	ˈsikkiːn ‘knife’ (4.29)	ˈkursi ‘chair’ (1.19)	ˈʕuʃʃ ‘nest’ (1.06)	ˈbujah ‘paint’ (1.02)
ˈmiʔðanah ‘minaret’	ˈʔaðaːn ‘calling for prayer’ (4.89)	ˈʔuðun ‘ear’ (2.38)	ˈaðnaːb ‘tails’ (1)	ˈqubbah ‘dome’ (3.68)	ˈxaruːf ‘lamb’ (1)	ˈʃaʕar ‘hair’ (1)	ˈtˤaːwlah ‘table’ (1.08)
ˈmasbaħ ‘swimming pool’	ˈsabbaːħ ‘swimmer’ (4.87)	ˈsabħah ‘rosary’ (1.4)	ˈsaħaːb ‘cloud’ (1.34)	nadˤˈdˤaːrah ‘goggles’ (4.74)	ˈdʒamal ‘camel’ (1.1)	ˈxajmah ‘tent’ (1.07)	ˈʃadʒarah ‘tree’ (1.17)
ˈmistˤarah ‘ruler’	ˈsatˤr ‘line’ (4.21)	ˈsaːtˤuːr ‘cleaver’ (1.27)	ˈsalatˤah ‘salad’ (1)	ˈhandasah ‘geometry set’ (3.75)	ɣazaːl ‘deer’ (1)	ħaliːb ‘milk’ (1.06)	ʕallaqah hanger (1.48)
ˈmudarradʒaːt ‘grandstands’	ˈdaradʒ ‘stairs’ (3.75)	durdʒ ‘drawer’ (1.25)	ˈdadʒaːdʒah ‘hen’ (1)	ħakam ‘referee’ (4.06)	timsaːħ ‘crocodile’ (1.08)	xaʃabah ‘piece of wood’ (1.12)	bunduqijah ‘rifle’ (1.02)
ˈmasaːr ‘lane’	sajˈjaːrah ‘car’ (4.61)	ˈsajr ‘treadmill’ (1.85)	ˈsaːħir ‘magician’ (1.04)	taˈqaːtˤuʕ ‘intersection’ (4)	ˈnadʒmah ‘star’ (1.17)	tˤaˈmaːtˤim ‘tomatoes’ (1)	ˈθuʕbaːn ‘snake’ (1.34)

Table 5.21: Stimuli list for Experiment 2B. Primary stress is indicated by the APA mark (ˈ) before stressed syllable. Average ratings for semantic association with targets are shown in parentheses under each word.

Procedures for familiarity, semantic transparency and visual stimuli ratings were identical to Experiment 2A. For familiarity rating, a one-way ANOVA with eight levels was conducted to compare the familiarity rating for the eight word types (targets, competitors in the baseline, phonological, −R+S, +R+S, and +R−S conditions, and the two unrelated word groups). Results showed what could be considered significant differences (although the p-value was slightly bigger than .05) in average familiarity rating among the eight word groups ($F(7, 98) = 2.15$, $p > 0.055$, see Table 5.22). Tukey pair-wise comparisons were also conducted to see if there were differences between the eight word groups. Results revealed that there were no significant differences between word groups (see Table 5.23).

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
variable	7.000	0.480	0.069	2.158	0.055
Residuals	48.000	1.524	0.032		

Table 5.22: One-way ANOVA to compare average familiarity rating across conditions.

	Difference	Lower	Upper	p-adjusted
Unrelated_1 - Target	0.199	-0.102	0.501	0.434
(+R+S) - Target	0.251	-0.051	0.553	0.169
Baseline - Target	0.266	-0.036	0.568	0.122
(+R-S) - Target	0.075	-0.227	0.377	0.993
Phonological - Target	0.063	-0.239	0.365	0.998
(-R+S) - Target	0.224	-0.078	0.526	0.287
Unrelated_2 - Target	0.194	-0.107	0.496	0.467
(+R+S) - Unrelated_1	0.051	-0.250	0.353	0.999
Baseline - Unrelated_1	0.066	-0.235	0.368	0.997
(+R-S) - Unrelated_1	-0.125	-0.426	0.177	0.891
Phonological - Unrelated_1	-0.136	-0.438	0.166	0.839
(-R+S) - Unrelated_1	0.025	-0.277	0.327	1.000
Unrelated_2 - Unrelated_1	-0.005	-0.307	0.297	1.000
Baseline - (+R+S)	0.015	-0.287	0.317	1.000
(+R-S) - (+R+S)	-0.176	-0.478	0.126	0.591
Phonological - (+R+S)	-0.188	-0.489	0.114	0.512
(-R+S) - (+R+S)	-0.027	-0.328	0.275	1.000
Unrelated_2 - (+R+S)	-0.056	-0.358	0.245	0.999
(+R-S) - Baseline	-0.191	-0.493	0.111	0.489
Phonological - Baseline	-0.203	-0.504	0.099	0.413
(-R+S) - Baseline	-0.042	-0.343	0.260	1.000
Unrelated_2 - Baseline	-0.071	-0.373	0.230	0.995
Phonological - (+R-S)	-0.012	-0.313	0.290	1.000
(-R+S) - (+R-S)	0.150	-0.152	0.451	0.766
Unrelated_2 - (+R-S)	0.120	-0.182	0.421	0.910
(-R+S) - Phonological	0.161	-0.141	0.463	0.692
Unrelated_2 - Phonological	0.131	-0.171	0.433	0.863
Unrelated_2 - (-R+S)	-0.030	-0.332	0.272	1.000

Table 5.23: Experiment 2B: Pair-wise comparisons of average familiarity rating across conditions.

With regard to semantic rating, a A one-way ANOVA showed a significant difference in average semantic ratings for stimuli groups ($F(6,\ 42) = 199.47$, $p > 0.001$. Tukey pair-wise comparisons demonstrated differences that matched the required specification for the stimuli described in Experiment 2A (see Tables 5.24 and 5.25 below). That is, semantic transparency means of competitors in the +R+S and −R+S conditions were significantly different from those in the baseline and all other conditions. They were also significantly different from the two groups of unrelated words used in the experiment. All other conditions did not significantly differ from the baseline or from each other.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
type	6.000	101.527	16.921	199.472	0.000
Residuals	42.000	3.563	0.085		

Table 5.24: Experiment 2B: One-way ANOVA to compare average semantic transparency rating across conditions.

	Difference	Lower	Upper	p-adjusted
(+R-S) - (-R+S)	-2.636	-3.118	-2.154	0.000
(+R+S) - (-R+S)	0.396	-0.085	0.878	0.169
Baseline - (-R+S)	-3.086	-3.568	-2.604	0.000
Phonological - (-R+S)	-3.046	-3.528	-2.565	0.000
Unrelated_1 - (-R+S)	-3.039	-3.521	-2.557	0.000
Unrelated_2 - (-R+S)	-3.014	-3.496	-2.532	0.000
(+R+S) - (+R-S)	3.032	2.550	3.514	0.000
Baseline - (+R-S)	-0.450	-0.932	0.032	0.081
Phonological - (+R-S)	-0.411	-0.893	0.071	0.141
Unrelated_1 - (+R-S)	-0.404	-0.885	0.078	0.154
Unrelated_2 - (+R-S)	-0.379	-0.860	0.103	0.211
Baseline - (+R+S)	-3.482	-3.964	-3.000	0.000
Phonological - (+R+S)	-3.443	-3.925	-2.961	0.000
Unrelated_1 - (+R+S)	-3.436	-3.918	-2.954	0.000
Unrelated_2 - (+R+S)	-3.411	-3.893	-2.929	0.000
Phonological - Baseline	0.039	-0.443	0.521	1.000
Unrelated_1 - Baseline	0.046	-0.435	0.528	1.000
Unrelated_2 - Baseline	0.071	-0.410	0.553	0.999
Unrelated_1 - Phonological	0.007	-0.475	0.489	1.000
Unrelated_2 - Phonological	0.032	-0.450	0.514	1.000
Unrelated_2 - Unrelated_1	0.025	-0.457	0.507	1.000

Table 5.25: Experiment 2B: Pair-wise comparisons of average semantic transparency rating across conditions

5.2.2 Predictions

Predictions in this experiment are identical to the predictions discussed in Experiment 2A. However, it was predicted that phonological competitors would attract fewer fixations and would cause less latency in RTs to targets relative to Experiment 2A due to the fact that they did not share the same onsets with targets (recall that the targets had an additional prefix so that they did not match on their initial consonants). In addition, as targets in this experiment were morphologically more complex than those in Experiment 2A, it was predicted that morphological processing would be more important for recognition and hence competitors in the root-related (+R+S, and +R−S) conditions would receive higher activation relative to the phonological competitors.

5.2.3 Results

5.2.3.1 Analyses of eyetracking data

The eyetracking data of 33 out of 35 participants were subject to analysis. The eyetracking data from two participants were excluded due to bad calibration. The procedures used in this experiment were identical to those used in Experiments 1 and 2A. Figure 5.14 shows the average proportions of fixation to targets, competitors, and unrelated items for all conditions. The time window that was subject to GCA analyses was between 200 and 1200 ms after word onset. Visualizing Figures 5.15 and 5.16 show fixation proportions to targets and competitors across conditions. Similar to Experiments 1 and 2A, a quasi-logistic GCA (Mirman, 2014; Mirman et al., 2008) was used to analyze the differences in target and competitor fixations across conditions.

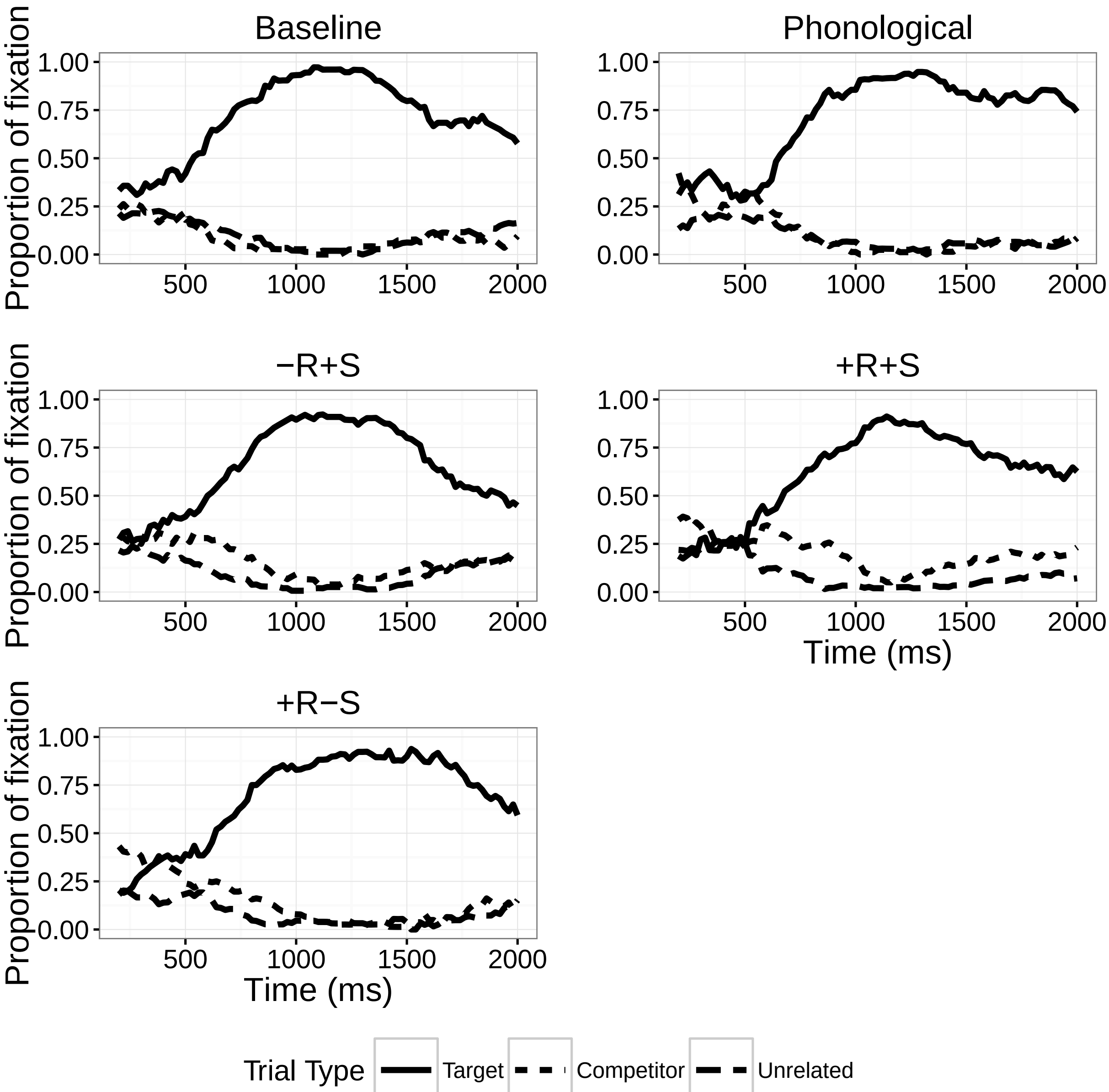

Figure 5.14: Fixation to targets, competitor, and unrelated for all conditions

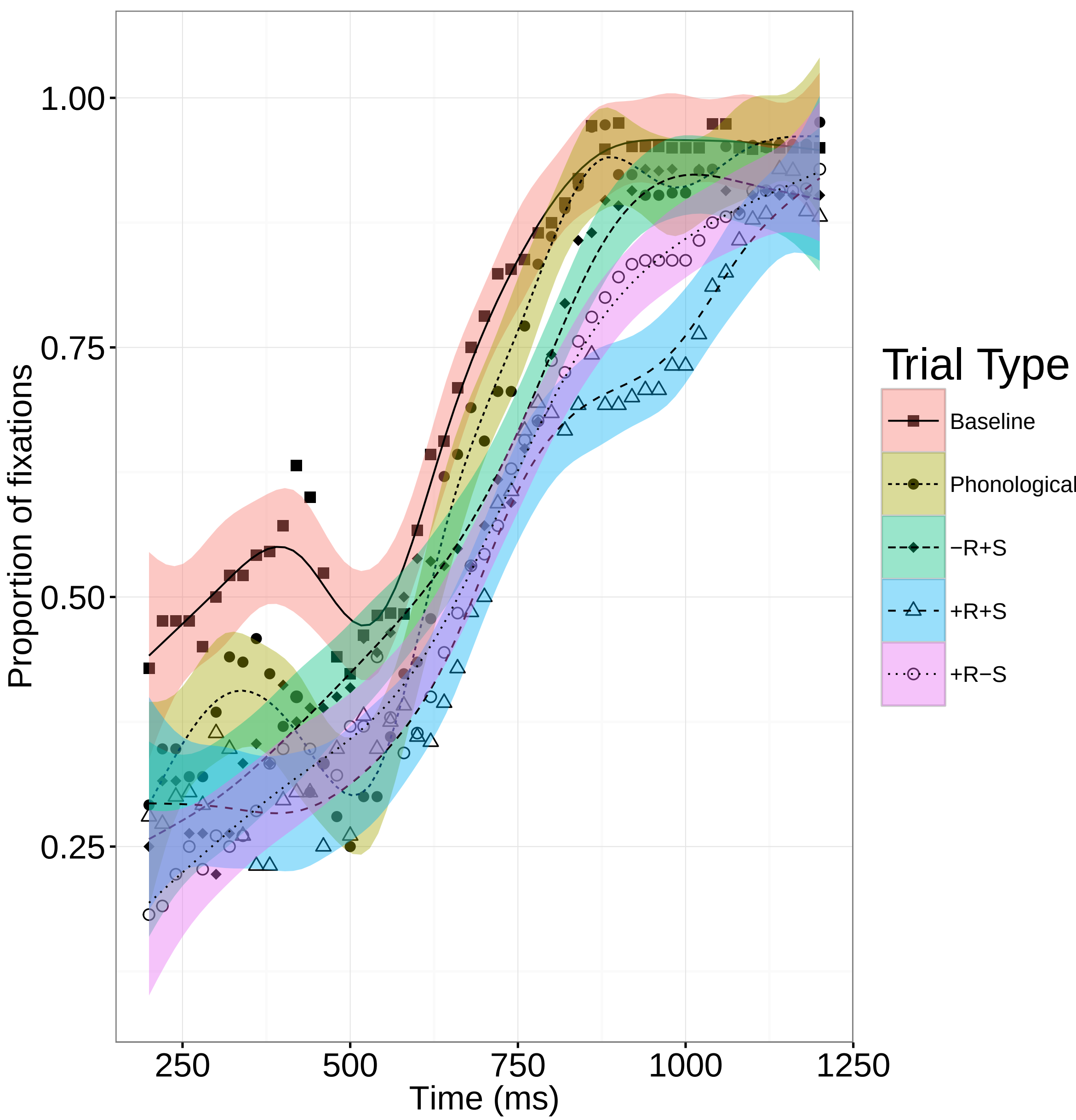

Figure 5.15: Target fixations for all conditions (LOESS smoothed lines were fit to the data)

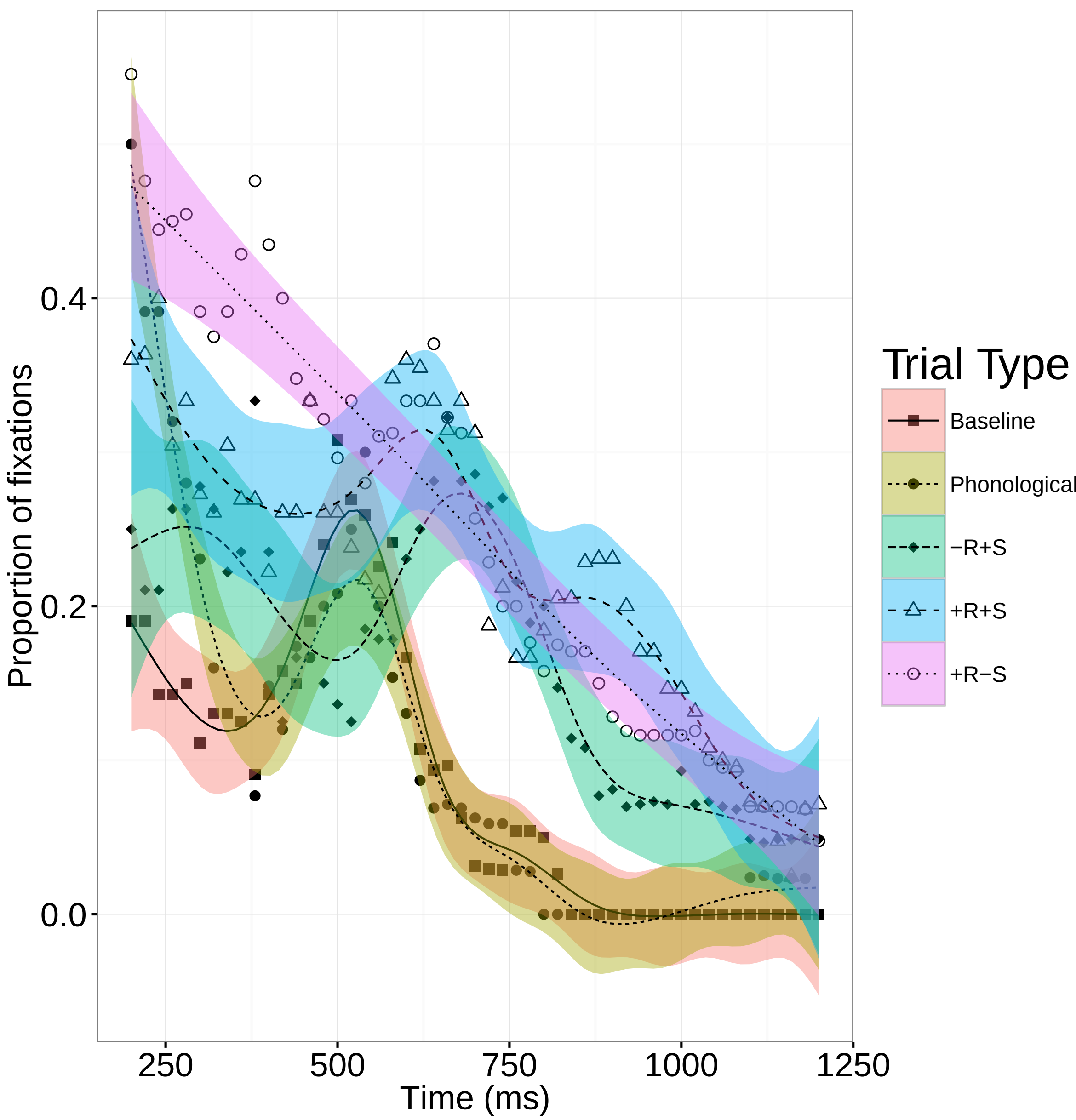

Figure 5.16: Competitor fixations for all conditions (LOESS smoothed lines were fit to the data)

5.2.3.2 Target and Competitor Fixations of experimental conditions versus baseline condition

This section describes target and competitor fixations in each of the four experimental conditions (phonological, −R+S, +R+S, and +R−S) relative to the baseline condition. The baseline condition is always treated as the reference condition.

5.2.3.2.1 Phonological versus Baseline

Comparing target fixation proportions in the phonological and baseline conditions, GCA results showed a significant effect of condition on the intercept (see Table 5.26) indicating that the overall mean of fixation proportions to targets in the baseline condition were higher than the overall mean of fixation to targets in the phonological condition. In addition, the comparison revealed a significant difference in the slope between the conditions captured by the linear term. The fixation curve in the phonological condition was less steeper than in the baseline condition (see Figure 5.17). No other significant differences were found between the two conditions.

	Estimate	Std. Error	t-value	p-value
(Intercept)	2.427	0.408	5.950	0.000
Linear	14.413	1.788	8.060	0.000
Quadratic	-0.528	1.404	-0.376	0.707
Cubic	-4.126	1.030	-4.004	0.000
Condition	-1.126	0.558	-2.019	0.043
Linear:Condition	2.983	0.904	3.300	0.001
Quadratic:Condition	0.518	0.858	0.604	0.546
Cubic:Condition	-0.451	0.817	-0.552	0.581

Table 5.26: Target fixation: empirical logit GCA results for Baseline (the reference condition) versus Phonological

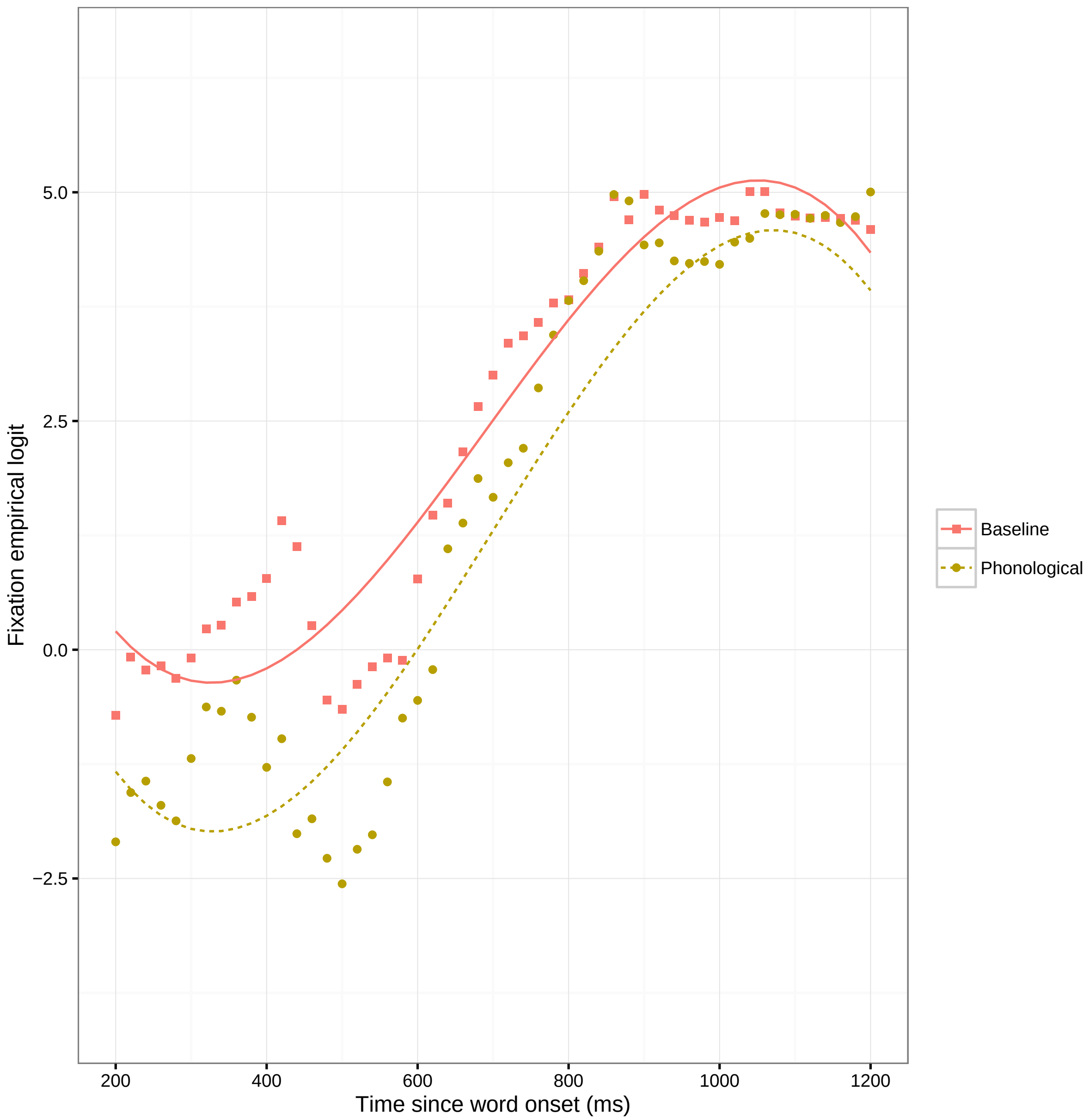

Figure 5.17: Target fixation: observed data (symbols) and GCA model fits (lines) for Baseline versus Phonological

For competitor fixation, GCA results showed that there was no significant effect of condition on the intercept (see Table 5.27). The overall mean of fixation to the phonological competitors was not significantly different from the overall mean of fixation to the baseline competitors. However, there were significant differences between the phonological and baseline conditions captured by all polynomial terms (see Figure 5.18). Fixation to phonological competitor was higher early in the timecourse but then dropped to have fewer fixations than fixations to the baseline pseudo-competitor.

	Estimate	Std. Error	t-value	p-value
(Intercept)	-4.328	0.198	-21.815	0.000
Linear	-5.485	1.172	-4.680	0.000
Quadratic	-0.035	1.133	-0.031	0.975
Cubic	1.760	0.945	1.862	0.063
Condition	0.263	0.196	1.342	0.180
Linear:Condition	-2.757	0.640	-4.310	0.000
Quadratic:Condition	3.700	0.614	6.027	0.000
Cubic:Condition	-2.189	0.594	-3.683	0.000

Table 5.27: Competitor fixation: Empirical logit GCA results for Baseline (the reference condition) versus Phonological

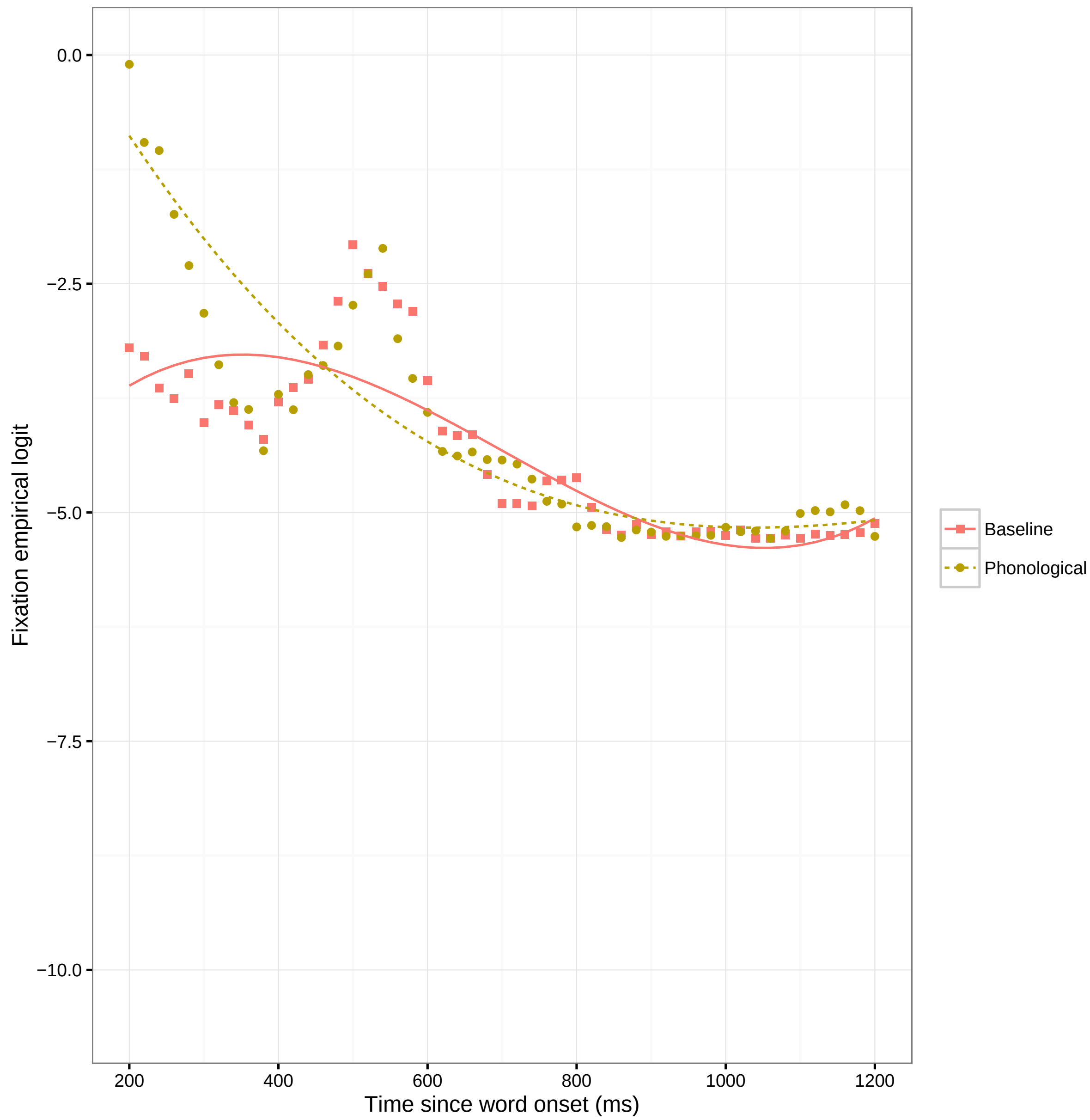

Figure 5.18: Competitor fixation: observed data (symbols) and GCA model fits (lines) for Baseline versus Phonological

These results are in line with what was predicted. Fixation to targets in the phonological condition were affected by the presence of phonological competitors compared to fixation to targets in the baseline condition. Compared to the results obtained from Experiment 2A, the current results showed that phonological competitors received fewer fixations (see

Figure 5.19 which compares phonological competitors' fixation in Experiment 2A versus 2B). This is attributed to the fact that unlike in Experiment 2A, they did not share onsets with targets (compare for example, farʃah / fiʃa:r in Experiment 2A to masbaħ / saħa:b in Experiment 2B).

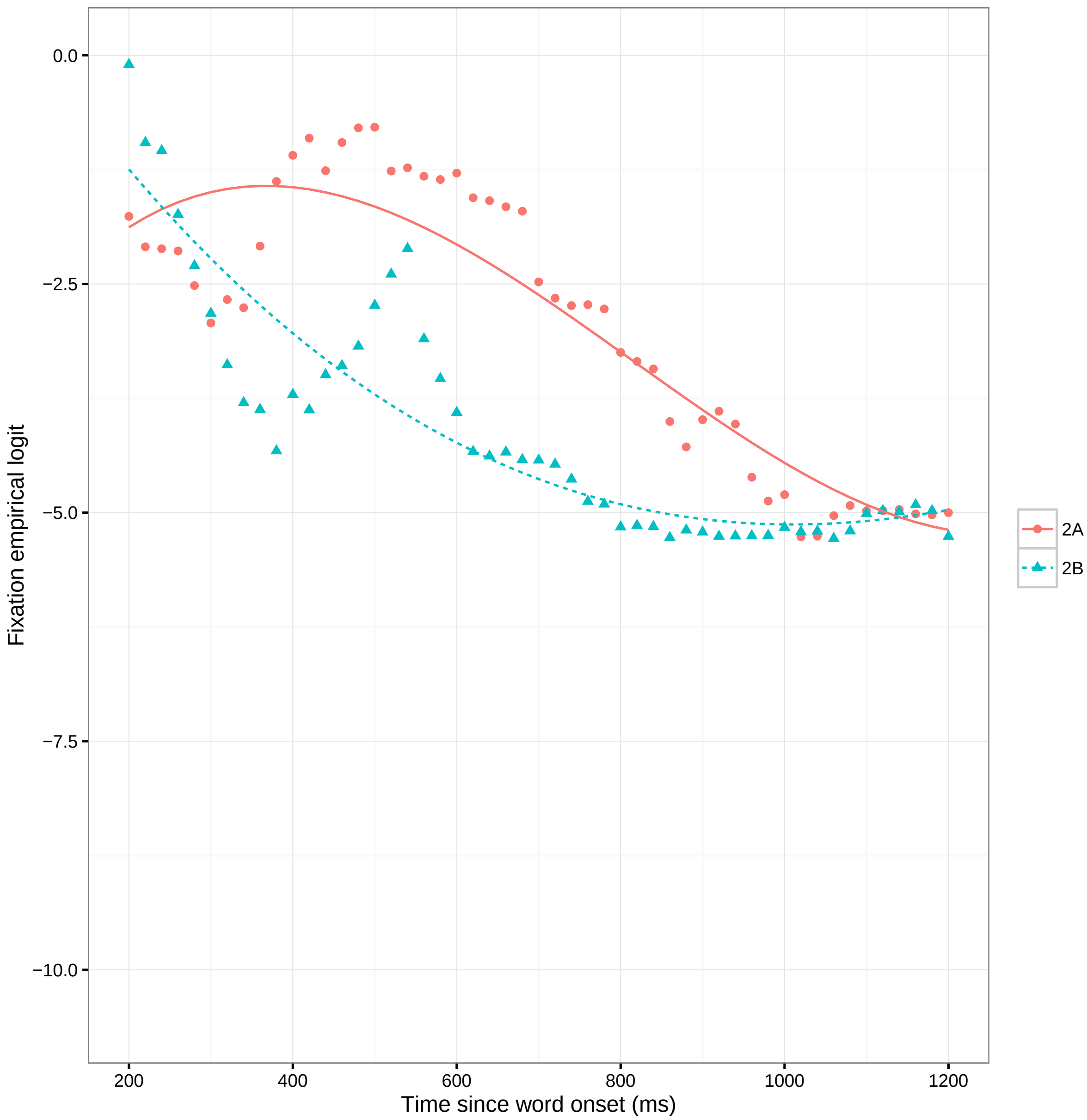

Figure 5.19: PHONOLOGICAL: Competitor fixation for Exp 2A versus Exp 2B

5.2.3.2.2 −R+S versus Baseline

Comparing target fixation in the baseline and −R+S conditions showed a significant effect of condition on the intercept. The overall mean of fixation to targets in the baseline condition was higher than that of the −R+S condition (see Table 5.28). No differences were captured by the linear, quadratic and cubic terms (see Figure 5.20). This difference in the overall mean of fixations to targets indicates that fixations to targets were affected by the presence of semantically related competitors.

	Estimate	Std. Error	t-value	p-value
(Intercept)	2.425	0.405	5.984	0.000
Linear	14.391	2.176	6.613	0.000
Quadratic	0.847	1.941	0.436	0.663
Cubic	-5.370	1.587	-3.383	0.001
Condition	-1.129	0.558	-2.025	0.043
Linear:Condition	1.074	0.949	1.132	0.258
Quadratic:Condition	0.293	0.864	0.339	0.735
Cubic:Condition	1.220	0.823	1.482	0.138

Table 5.28: Target fixation: empirical logit GCA results for Baseline (the reference condition) versus -R+S

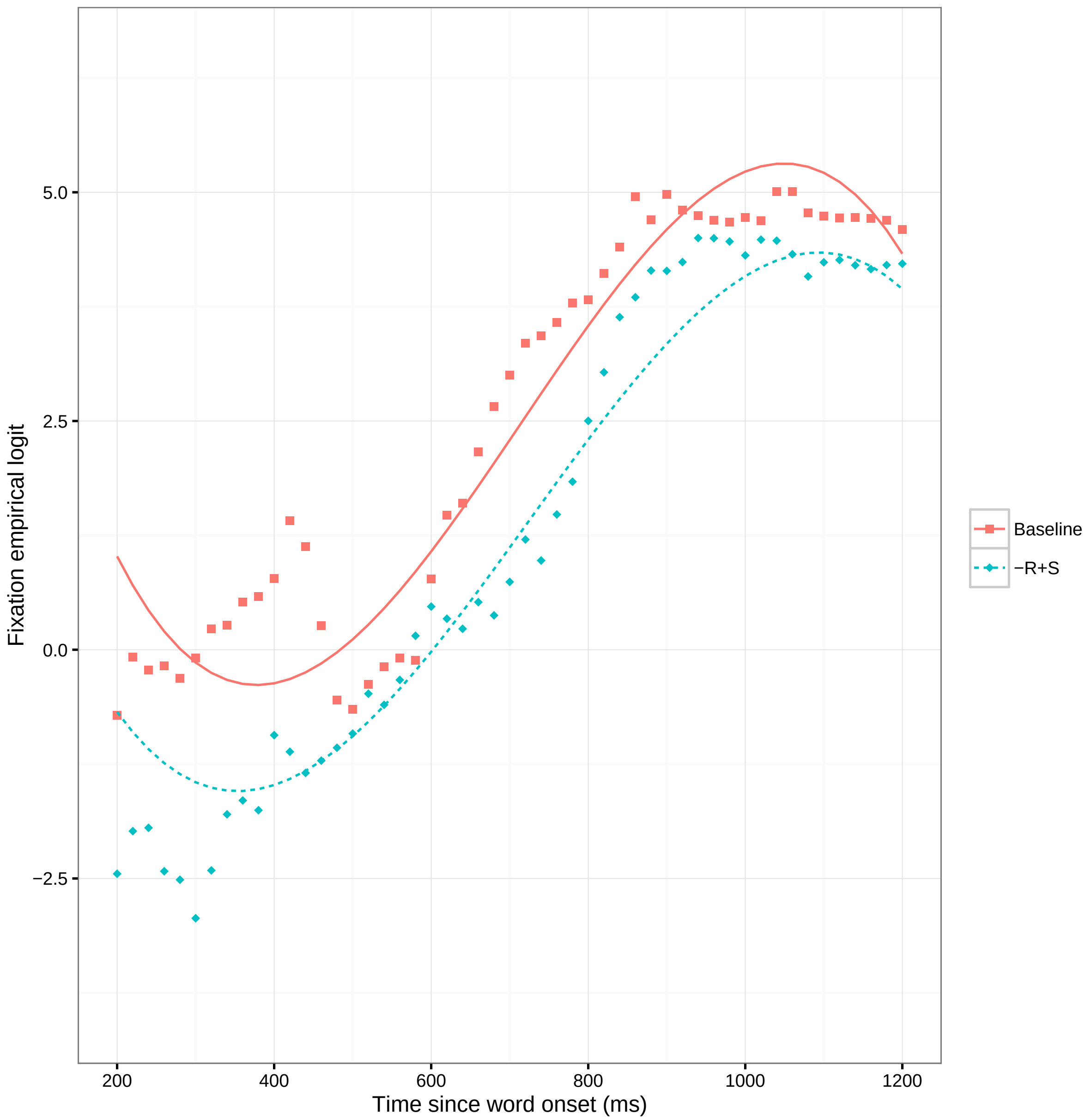

Figure 5.20: Target fixation: observed data (symbols) and GCA model fits (lines) for Baseline versus -R+S

With regard to competitor fixation, results showed a significant effect of condition on the intercept (see Table 5.29). −R+S competitors received more looking than the baseline pseudo-competitor. A significant difference was also captured by cubic terms (see Figure 5.21). Looking at the −R+S curve we can see that fixation to −R+S competitors started early in the timecourse and continued until around 1000 ms. after word onset.

	Estimate	Std. Error	t-value	p-value
(Intercept)	-4.306	0.210	-20.533	0.000
Linear	-4.548	1.483	-3.067	0.002
Quadratic	-1.566	1.661	-0.943	0.346
Cubic	2.904	1.200	2.420	0.016
Condition	0.953	0.403	2.364	0.018
Linear:Condition	-0.370	0.754	-0.490	0.624
Quadratic:Condition	0.728	0.694	1.050	0.294
Cubic:Condition	-3.309	0.660	-5.013	0.000

Table 5.29: Competitor fixation: Empirical logit GCA results for Baseline (the reference condition) versus -R+S

These results confirm the results obtained from Experiments 1 and 2A which have demonstrated an early and strong effect of semantic association in SWR in Arabic. These results provide support for the previous findings on the effect of semantic association in word recognition (Apfelbaum et al., 2011; Collins & Loftus, 1975; Hutchison, 2003; Yee & Sedivy, 2006). However, these results are not in line with previous cross-modal priming studies on Arabic SWR in which semantically associated (but phonologically and morphologically unrelated) prime/target pairs failed to produce significant priming effect (Boudelaa & Marslen-Wilson, 2000, 2015). The different results can be attributed to the differences in paradigms. The eyetracking methodology seems to be more sensitive to semantic activation than the priming paradigm.

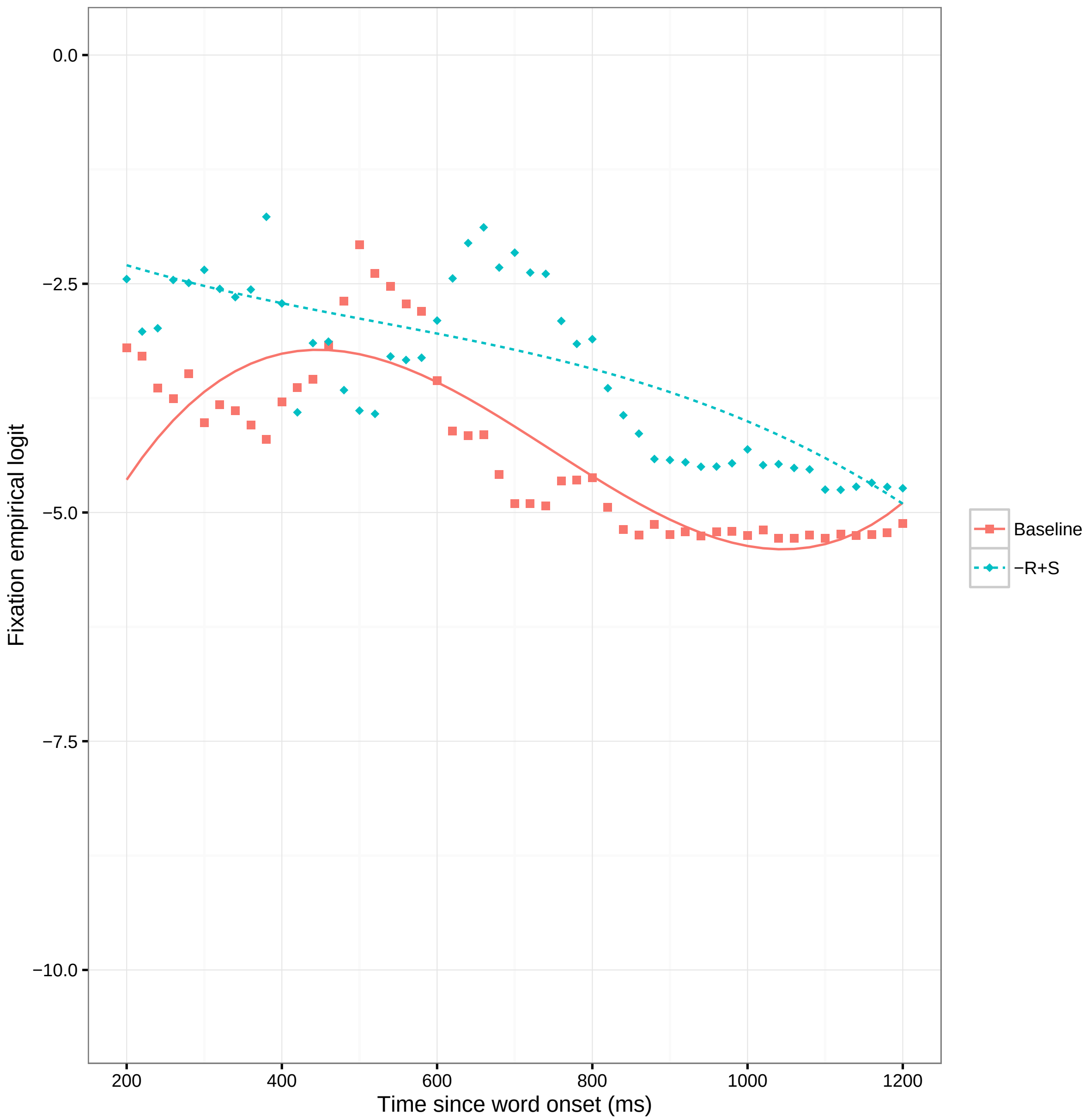

Figure 5.21: Competitor fixation: observed data (symbols) and GCA model fits (lines) for Baseline versus -R+S

5.2.3.2.3 +R+S versus Baseline

Comparing target fixations in the baseline and the +R+S conditions, results revealed a significant effect of condition on the intercept (see Table 5.30). The overall mean of fixation to targets in baseline condition was higher than the overall mean of fixation to targets in the +R+S condition. There were also significant effects captured by the quadratic and cubic terms (see Figure 5.22). These results indicate that target fixation was affected by the presence of +R+S competitors.

	Estimate	Std. Error	t-value	p-value
(Intercept)	2.380	0.400	5.953	0.000
Linear	15.436	1.842	8.382	0.000
Quadratic	-0.483	1.350	-0.358	0.721
Cubic	-3.969	1.142	-3.476	0.001
Condition	-2.398	0.648	-3.703	0.000
Linear:Condition	0.682	0.869	0.785	0.432
Quadratic:Condition	3.525	0.814	4.333	0.000
Cubic:Condition	1.867	0.790	2.362	0.018

Table 5.30: Target fixation: empirical logit GCA results for Baseline (the reference condition) versus +R+S

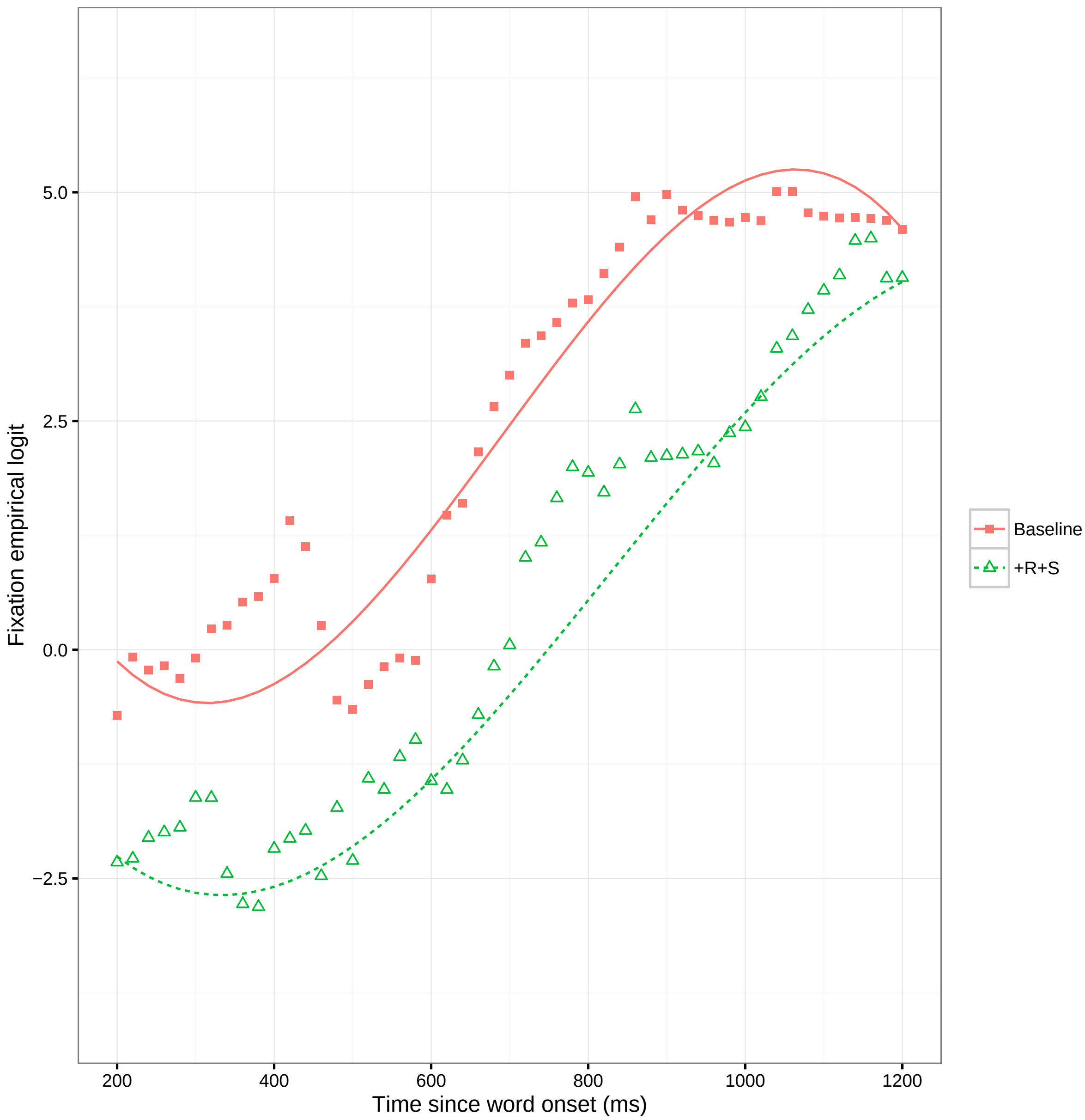

Figure 5.22: Target fixation: observed data (symbols) and GCA model fits for Baseline versus +R+S

Competitor fixations' results showed that there were significant effects of condition on the intercept (see Table 5.31). The overall mean of fixation to +R+S condition was higher than that of the baseline pseudo-competitor. There were also significant differences on the curvature captured by the quadratic and cubic terms indicating steeper slopes before and after the main inflection of the curve (see Figure 5.23). All these results indicate strong activation of +R+S competitors during the SWR process.

	Estimate	Std. Error	t-value	p-value
(Intercept)	-4.292	0.227	-18.891	0.000
Linear	-6.097	1.204	-5.064	0.000
Quadratic	-1.224	1.686	-0.726	0.468
Cubic	2.730	1.240	2.203	0.028
Condition	1.450	0.459	3.158	0.002
Linear:Condition	1.128	0.773	1.459	0.145
Quadratic:Condition	-1.427	0.732	-1.949	0.051
Cubic:Condition	-3.044	0.710	-4.286	0.000

Table 5.31: Competitor fixation: Empirical logit GCA results for Baseline (the reference condition) versus +R+S

These results were in line with the results obtained from Experiments 1 and 2A of the current work. They were also consistent with previous studies that have found that morphologically related words with transparent semantic relatedness produced significant priming effect (Gonnerman et al., 2007; Marslen-Wilson et al., 1994; Plaut & Gonnerman, 2000). They also provide support to previous findings that have highlighted the importance of the Arabic consonantal root in SWR (Alamri & Zamuner, 2015; Boudelaa & Marslen-Wilson, 2000, 2015; Ussishkin et al., 2015).

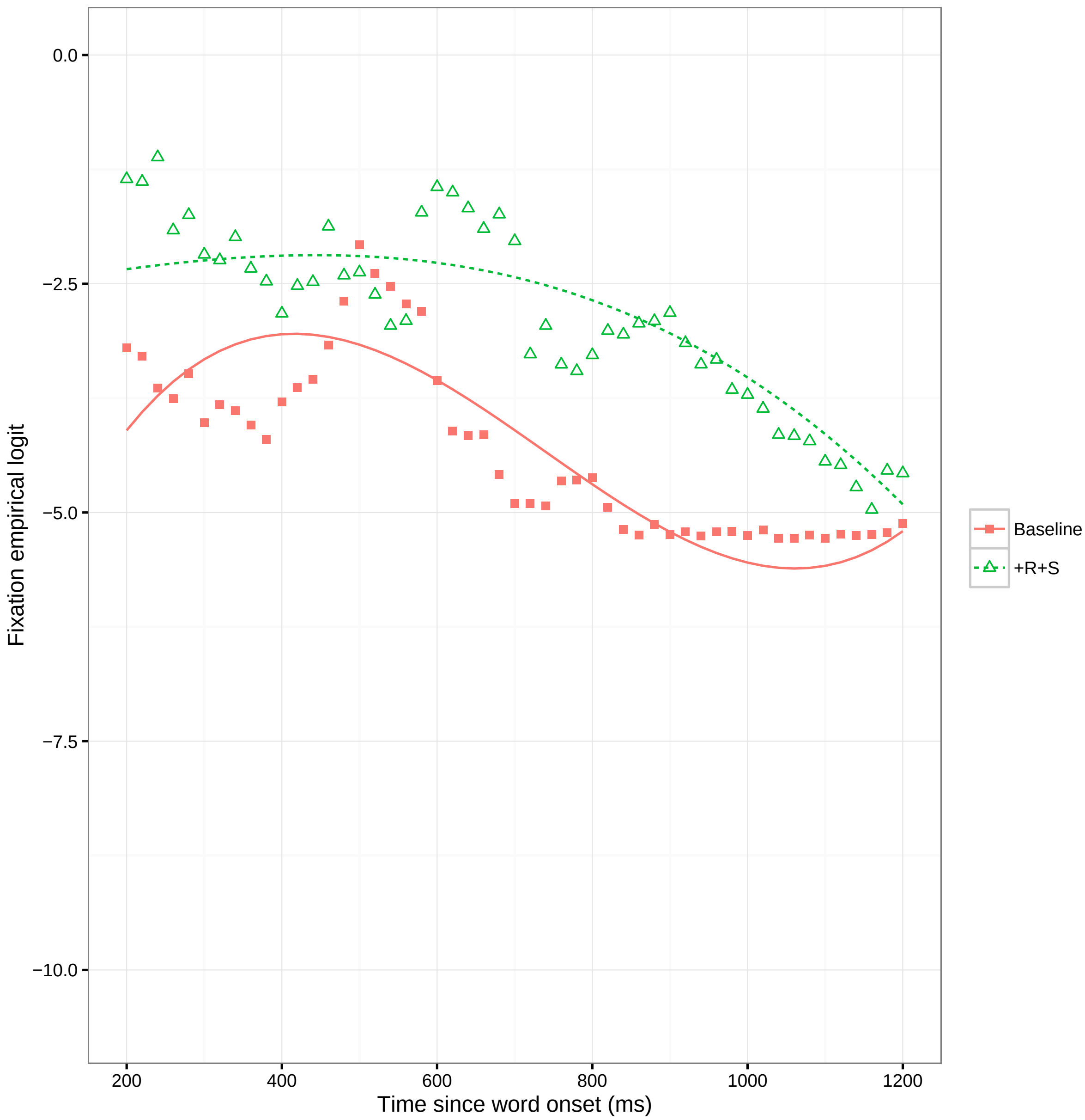

Figure 5.23: Competitor fixation: observed data (symbols) and GCA model fits for Baseline versus +R+S

5.2.3.2.4 +R−S versus Baseline

Comparing the baseline and +R−S conditions, results showed that there was a significant difference between the overall means of fixation to targets in the two conditions reflected in the significant effect of condition on the intercept (see Table 5.32). Fixations to targets in the baseline condition were greater than fixations to targets in +R−S condition. There was also a significant difference captured by the linear term (see Table 5.33) indicating faster rate of fixation to targets in the baseline condition relative to the +R−S condition. These differences indicate that fixation to targets was affected by the presence of +R−S competitors.

	Estimate	Std. Error	t-value	p-value
(Intercept)	2.639	0.362	7.285	0.000
Linear	13.707	1.879	7.295	0.000
Quadratic	-0.190	1.434	-0.132	0.895
Cubic	-4.019	1.093	-3.676	0.000
Condition	-1.735	0.571	-3.037	0.002
Linear:Condition	4.208	1.012	4.159	0.000
Quadratic:Condition	0.613	0.945	0.648	0.517
Cubic:Condition	0.772	0.878	0.880	0.379

Table 5.32: Target fixation: empirical logit GCA results for Baseline (the reference condition) versus +R-S

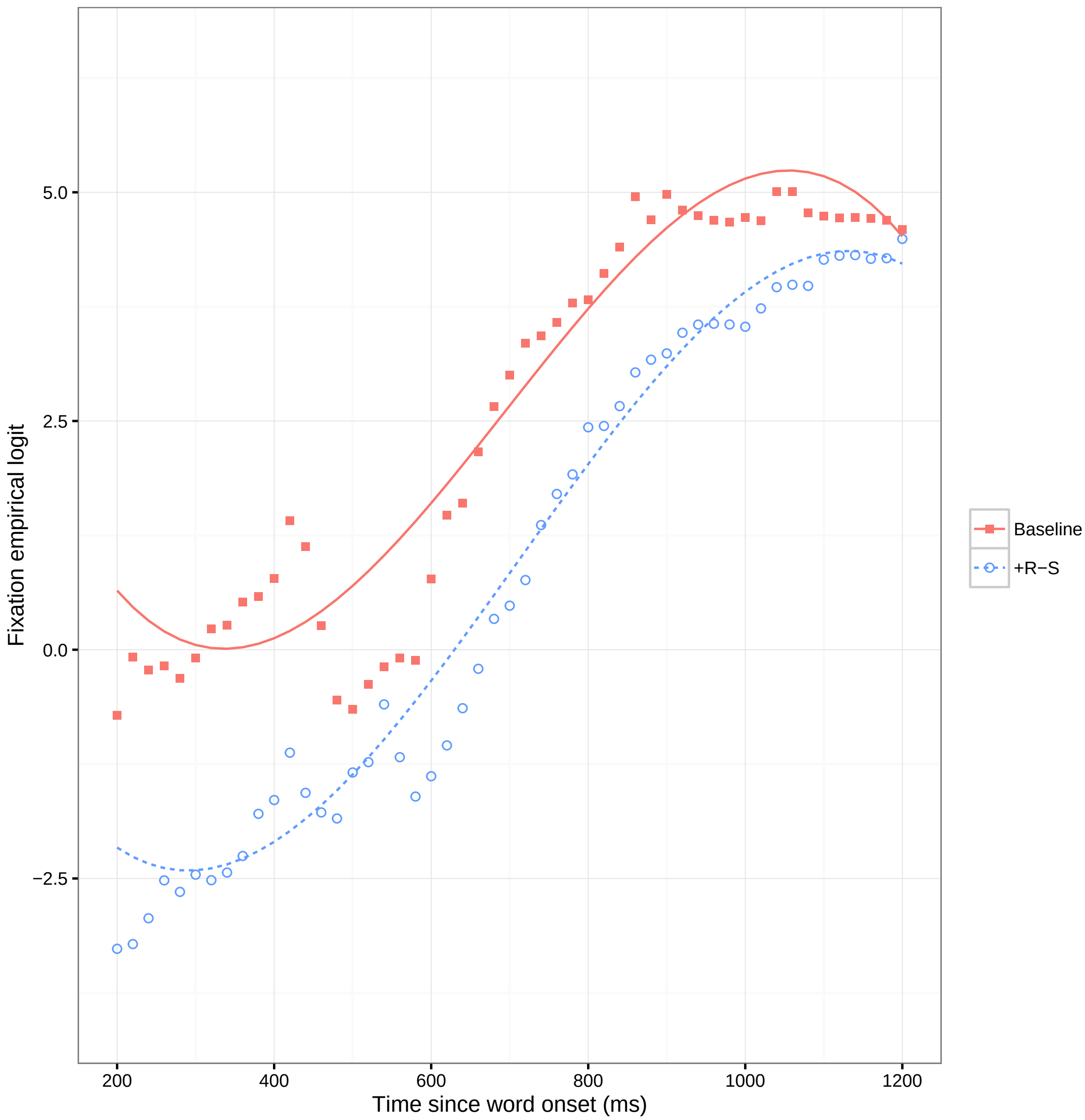

Figure 5.24: Target fixation: observed data (symbols) and GCA model fits for Baseline versus +R-S

As for competitor fixations, there was a significant effect of condition on the intercept (see Table 5.33). The overall means of fixations to +R−S competitors was significantly higher than that of the baseline pseudo-competitor. In addition there were significant differences captured by all polynomial terms (see Figure 5.25).

	Estimate	Std. Error	t-value	p-value
(Intercept)	-4.281	0.219	-19.534	0.000
Linear	-5.676	1.368	-4.148	0.000
Quadratic	-0.697	1.455	-0.479	0.632
Cubic	2.213	1.218	1.817	0.069
Condition	1.271	0.378	3.367	0.001
Linear:Condition	-3.037	0.846	-3.589	0.000
Quadratic:Condition	1.563	0.796	1.963	0.050
Cubic:Condition	-1.933	0.744	-2.599	0.009

Table 5.33: Competitor fixation: Empirical logit GCA results for Baseline (the reference condition) versus +R-S

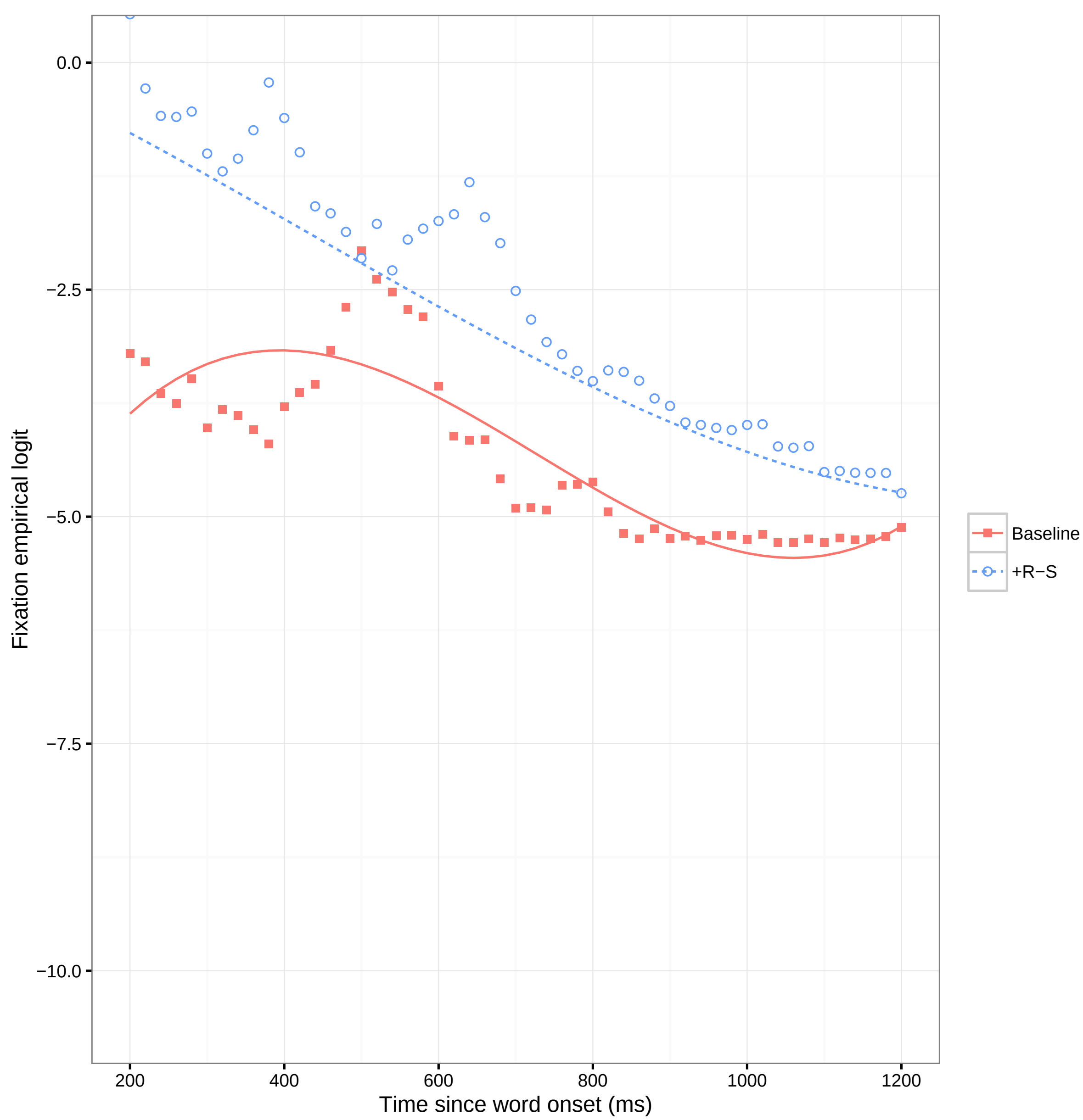

Figure 5.25: Competitor fixation: observed data (symbols) and GCA model fits for Baseline versus +R-S

Fixations to targets in the +R−S condition were affected by the presence of semantically opaque root-related competitors. These results confirm the results obtained from Experiment 2A. However, the effect of +R−S competitors was stronger in this experiment compared to Experiment 2A (see Figure 5.26 which compares +R−S competitors' fixation in Experiment 2A versus 2B). This is attributed to the fact that targets in this experiment were morphologically more complex than targets in Experiment 2A. It seems that when words are morphologically complex, word recognition relies more on morphological processing (this will be elaborated in Section 5.2.4).

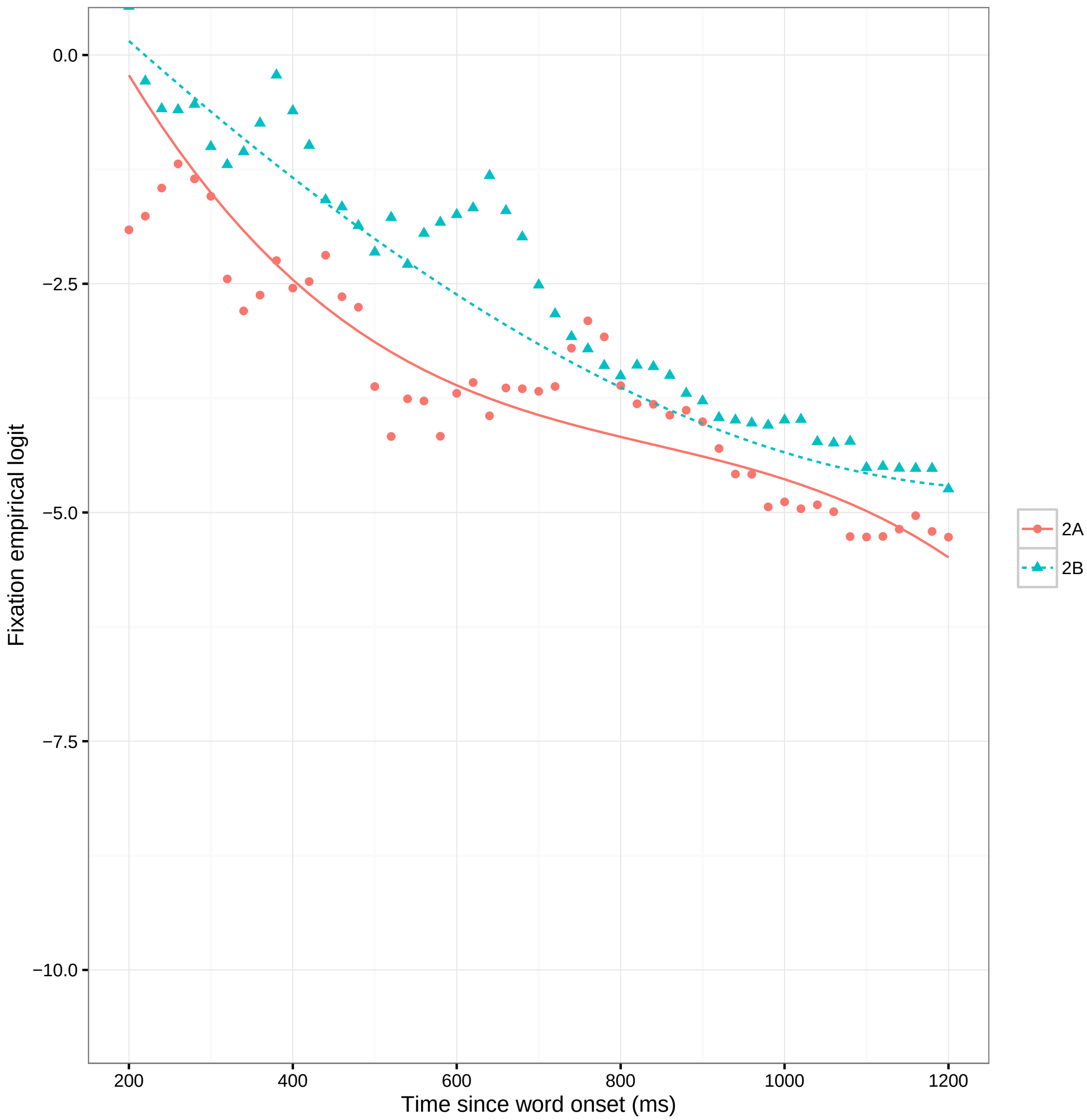

Figure 5.26: +R-S: Competitor fixation for Exp 2A versus Exp 2B

5.2.3.3 Pairwise comparisons of competitor fixations

In this section, two pair-wise comparisons are reported. In the first one, competitor fixations in the +R+S and +R−S conditions were compared to see if semantic transparency plays a role in root activation in SWR in Arabic. In the second comparison, competitor fixations in the phonological and +R−S conditions were compared to see whether morphological effects are separable from mere phonological effects.

5.2.3.3.1 +R+S versus +R−S

In this analysis, I compare fixations to the semantically transparent root-related competitors in the +R+S condition (e.g., *sabbaːħ* 'swimmer') to the semantically opaque root-related competitors in the +R−S condition (e.g., *sabħah* 'rosary'). The competitors in both conditions were root-related to targets (e.g., *masbaħ* 'swimming pool'). The results showed no significant effect of condition on the intercept indicating similar overall means of fixation. Curve analysis revealed no effect on the linear or quadratic terms. The only significant effect was captured by the cubic terms (see Table 5.34 and Figure 5.27). The difference on the cubic term was reflected in a steeper curve before and after the main inflection of the +R−S curve. The +R−S curve started to drop down around 600 ms. after word onset. This difference can be attributed as an effect of semantic transparency. However, the cubic effect is less informative in the absence of other effects as it is only sensitive to changes in the asymptotic tails of the curve (Mirman, 2014; Mirman et al., 2008).

	Estimate	Std. Error	t-value	p-value
(Intercept)	-2.662	0.459	-5.803	0.000
Linear	-6.642	1.554	-4.273	0.000
Quadratic	-1.524	1.220	-1.250	0.211
Cubic	-0.500	1.184	-0.423	0.672
Condition	-0.384	0.569	-0.675	0.500
Linear:Condition	-1.187	0.930	-1.277	0.202
Quadratic:Condition	0.839	0.866	0.968	0.333
Cubic:Condition	1.780	0.843	2.112	0.035

Table 5.34: Competitor fixation: Empirical logit GCA results for Root: +R+S (the reference condition) versus +R-S

The difference obtained from this comparison was smaller than that obtained from Experiment 2A. It seems that in the context of affixed words, morphological processing is

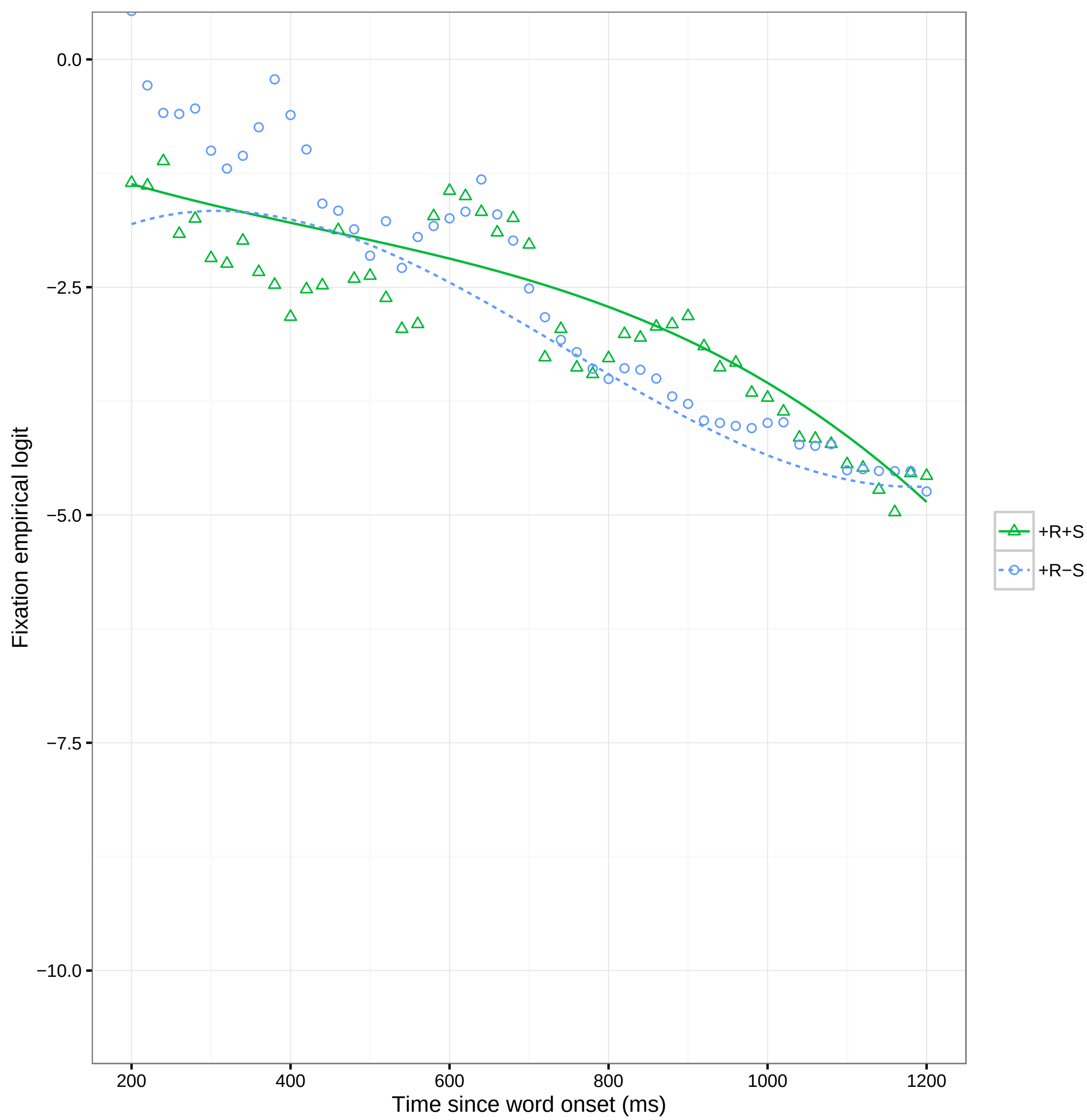

Figure 5.27: Competitor fixation: observed data (symbols) and GCA model fits for +R+S versus +R-S

not conditioned by semantic transparency. The results showed comparable fixation to root-related words regardless of semantic transparency. This finding provides support to the previous findings that have comparable priming effects for semantically transparent and semantically opaque root-related words in SWR in Arabic (Boudelaa & Marslen-Wilson, 2000, 2015; Schluter, 2013). This finding cannot be accommodated within the single-route distributed connectionist model discussed earlier in which morphology is considered as a part of an interlevel unit that computes the phonological and semantic relationships among words and hence is faster in processing words that are phonologically and or semantically related. +R+S competitors were similar to targets in form and meaning whereas +R−S competitors were similar in form but not in meaning, however, they received comparable fixation. Therefore, the results can only be accounted for by the parallel dual route model in which a morphological decompositional route processes complex words via their morphemic constituents. More discussion of these models is presented in section 5.2.4 below.

5.2.3.3.2 Phonological versus +R−S

In this analysis, I compare fixation to the phonologically related (but semantically and morphologically unrelated) competitors in the phonological condition (e.g., *saħaːb* 'cloud') to the semantically opaque root-related competitors in the +R−S condition (e.g., *sabħah* 'rosary'). The competitors in both conditions shared similar phonological overlap with targets (e.g., *masbaħ* 'swimming pool'), however, unlike in Experiment 2A, none of the two competitor types shared the same onset with target. In Experiment 2A, when both conditions shared the same onset and similar overall phonological overlap with targets, phonological competitors received higher activation. This was attributed to an inhibitory effect from the morphological parser that hindered the activation of +R−S competitors because of their meaning dissimilarity to targets.

In this experiment, the results of the comparison showed that +R−S competitors received higher fixation than phonological competitors. There was a significant effect of condition on the intercept. The overall mean of fixations to +R−S competitors was larger than the overall mean of fixation to phonological competitors. There was a significant effect on curvature captured by the quadratic term. In addition, there was a marginal effect captured by the linear term. No significant effect was captured by the cubic terms (see Table 5.35 and Figure 5.28).

	Estimate	Std. Error	t-value	p-value
(Intercept)	-4.075	0.206	-19.744	0.000
Linear	-7.177	1.528	-4.696	0.000
Quadratic	2.435	1.366	1.783	0.075
Cubic	0.392	1.175	0.333	0.739
Condition	1.071	0.456	2.349	0.019
Linear:Condition	-1.375	0.822	-1.674	0.094
Quadratic:Condition	-2.287	0.790	-2.895	0.004
Cubic:Condition	0.663	0.754	0.879	0.379

Table 5.35: Competitor fixation: Empirical logit GCA results for Phonological (the reference condition) versus +R-S

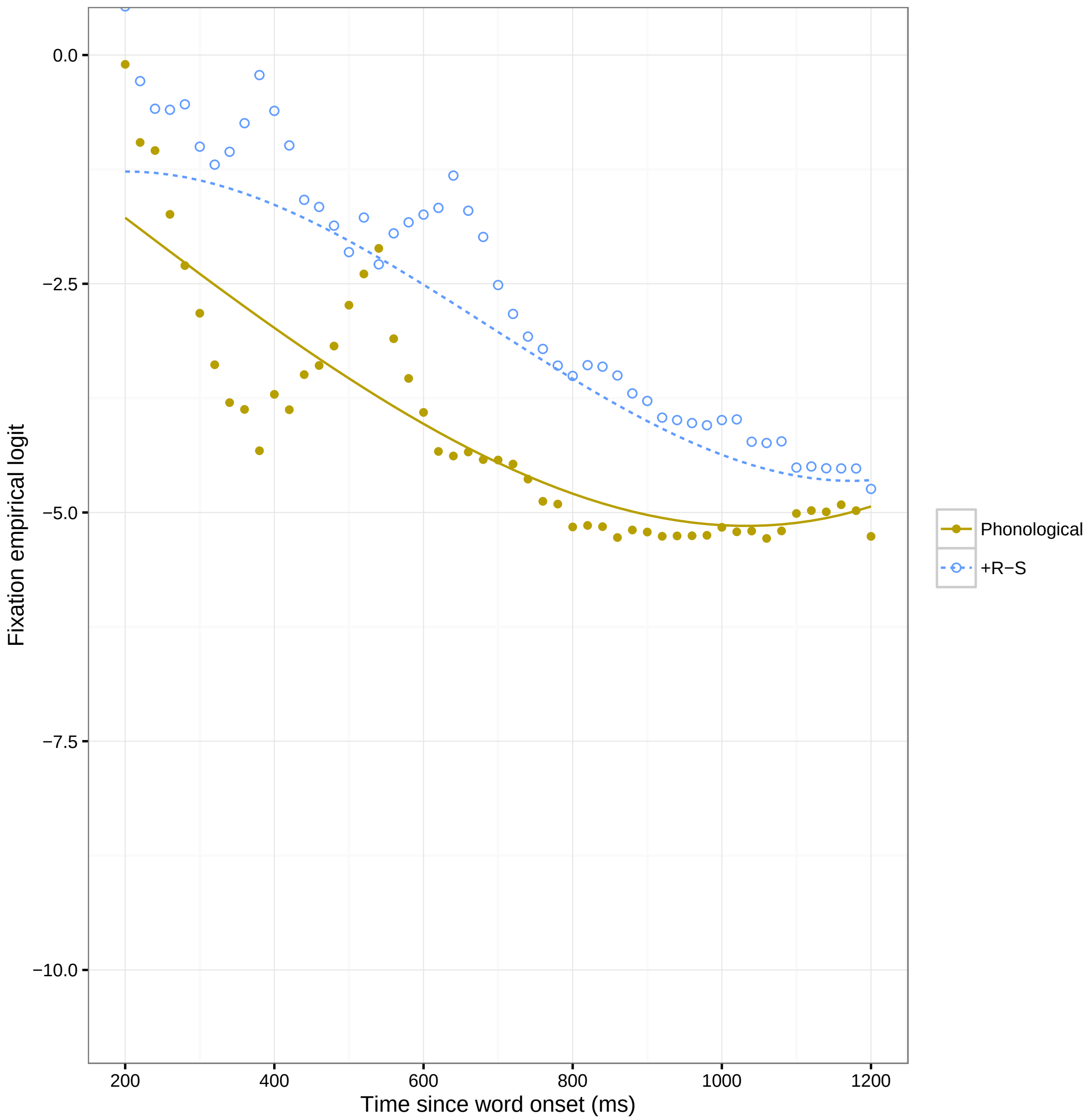

Figure 5.28: Competitor fixation: observed data (symbols) and GCA model fits for Phonological versus +R-S

The results of this comparison were as predicted. Although +R−S and phonological competitors shared similar amounts of phonological overlap with targets and they did not significantly differ from each other in terms of semantic transparency to targets, +R−S competitors received higher activation. Therefore, this higher activation is attributed to morphological activation and is considered independent from phonological and semantic effects. These results are different from the results obtained from Experiment 2A in which phonological and +R−S competitors shared onsets with targets. They also had similar overall phonological overlap with targets. So, the question that arises here is why phonological competitors received higher activation in Experiment 2A but low activation in Experiment 2B? The answer to this question may be found in the important role of onsets in phonological activation. As targets in Experiment 2B were all prefixed and thus did not match both types of competitors in the onset position, the mere phonological competitors did not receive high activation. This would be in line with previous findings that have highlighted the importance of onset in phonological activation in word recognition (e.g., Apfelbaum et al., 2011; Marslen-Wilson, 1987; Marslen-Wilson & Zwitserlood, 1989; Radeau et al., 1995; Slowiaczek et al., 1987). On the other hand, +R−S competitors received higher activation in Experiment 2B than in Experiment 2A because targets in Experiment 2B were morphologically more complex (prefixed) than targets in Experiment 2A. The results suggested that prefixed words in Arabic are processed by a morphological decomposition route and morphological relatives belonging to the same root are activated.

5.2.3.4 RT data

Data from the test trials of all the 33 participants were included in the analyses of response times. The data of the two participant that were removed from the eyetracking data were also removed from RTs data. Incorrect responses were also excluded from analysis (4 trial: 1 −R+S; 1 +R+S; 2 +R−S). In addition, trials in which a software error occurred were removed (7 trials: 3 baseline, 1 −R+S, 1 +R+S, and 2 +R−S trials). So, out of 245 experimental trials, 11 trials were trimmed and 244 were subject to analysis. Table 5.36 shows mean RTs and standard deviations across conditions. Results showed that participants took shorter time to click on target images in the baseline condition than in all the other conditions. RTs to phonological targets were the longest among all experimental conditions. RTs to targets in the −R+S and +R−S condition were the shortest among conditions. Finally RTs to targets in the +R+S condition were longer than RTs to targets in −R+S, and +R−S. These results are identical to the results obtained from Experiment 2A.

Trial type	Mean	St.D.
Baseline	1214.522	405.123
Phonological	1257.878	313.578
-R+S	1265.340	315.449
+R+S	1295.872	333.256
+R-S	1294.273	356.564

Table 5.36: Exp 2B: Summary of response time means and standard deviations across trial types

Similar to Experiment 2A, Linear Mixed-Effects Modelling (LMEMs) was used to assess the impact of condition (trial type) on reaction time. LMEMs estimated both fixed effects (condition), and random effect (participants). The baseline condition was treated as a reference level to estimate parameters for each of the remaining conditions. LMEMs produced pair-wise comparisons for the baseline condition with each of the other conditions. Results showed that there were significant differences between RTs in the baseline condition and all other condition (see Table 5.37). Pair-wise comparisons revealed no significant differences in RTs among conditions (see Table 4.19).

	Estimate	Std. Error	t-value	p-value
(Intercept)	1135.684	40.381	28.124	0.000
Phonological	120.021	51.226	2.343	0.019
-R+S	91.223	54.754	1.666	0.096
+R+S	174.281	56.349	3.093	0.002
+R-S	133.602	53.701	2.488	0.013

Table 5.37: Exp 2B: Linear Mixed-Effects model comparing response times across trial types (Baseline is the reference condition).

	Estimate	Std. Error	z-value	Pr(>|z|)
Phonological vs. -R+S	-28.799	54.850	-0.525	0.953
Phonological vs. +R+S	54.260	54.881	0.989	0.754
Phonological vs. +R-S	13.581	51.745	0.262	0.994
+R+S vs. -R+S	83.058	65.179	1.274	0.577
+R-S vs. -R+S	42.379	58.323	0.727	0.885
+R+S vs. +R-S	-40.679	55.506	-0.733	0.883

Table 5.38: Exp 2B: Pairwise comparisons of the mixed effects analysis for response times across trial types

These results are partially in line as predicted. RTs to targets in all conditions differed from RTs to targets in the baseline condition except for the −R+S which was only marginally significant. These results indicate that the presence of images of competitors sharing phonological, semantic or morphological features with targets had significant effects on the recognition of targets. These results are also in line with the results obtained from eyetracking data in this experiment which revealed significant differences in target and competitor fixation between each of the experimental conditions and the baseline condition.

5.2.4 Discussion

This experiment was conducted to investigate root activation in spoken word recognition in Arabic as a function of semantic transparency and phonological similarity using targets that were morphologically more complex than targets in Experiment 2A. Results showed that participants looked more to targets than to competitors and more to competitors than to unrelated images. When targets were presented with phonological competitors that shared three or more segments with targets but NOT including onsets (e.g., *saħ aːb* 'cloud'/*masbaħ* 'swimming pool'), fixation to targets was affected by the presence of these phonological competitors. However, the effect was smaller compared to the effect obtained from Experiment 2A in which targets and competitors shared onsets. These results highlight the importance of onset similarity in phonological activation in SWR in Arabic and provide support for previous studies that have found similar effect of onset familiarity using the priming paradigm (e.g., Marslen-Wilson, 1987; Marslen-Wilson & Zwitserlood, 1989; Radeau et al., 1995; Slowiaczek et al., 1987) as well as the visual world paradigm (Allopenna et al., 1998; Dahan et al., 2001; Tanenhaus et al., 1995).

When targets were presented with competitors that were semantically associated but phonologically and morphologically unrelated to targets (e.g., nadˤˈdˤaːrah 'goggles' / *masbaħ* 'swimming pool'), fixations to targets were significantly affected by the presence of competitors. Participants looked more at the competitors in the semantic condition than to the pseudo-competitors in the baseline condition. Fixations to targets were affected by the presence of semantic competitors. Partcipants looked more to targets in the semantic condition than to targets in the baseline condition. These results support previous semantic effects obtained from previous priming (e.g., Collins & Loftus, 1975; Hutchison, 2003; Marslen-Wilson et al., 1996; Marslen-Wilson & Zwitserlood, 1989; Moss et al., 1997) eye-tracking studies (Apfelbaum et al., 2011; Huettig & Altmann, 2005; McMurray et al., 2003; Yee & Sedivy, 2006).

Fixations results also showed that competitors in the root-related conditions (+R+S and +R−S) attracted more fixations than the pseudo-competitors of the baseline condition. When these two conditions were compared to each other (+R+S versus +R−S), no significant differences were found between the two conditions except for a significant difference captured by the cubic term which cannot be (alone) taken as an evidence for the effect of semantic transparency in SWR in Arabic. Therefore, these results are at odds with previous findings that have argued for graded effects of semantic transparency in complex word recognition (e.g., Giraudo & Grainger, 2000; Gonnerman et al., 2007; Kielar & Joanisse, 2010, 2011; Longtin et al., 2003; Marslen-Wilson et al., 1994; Plaut & Gonnerman, 2000), at least in the context of Arabic prefixed words. The results, however, are consistent with previous findings that have highlighted the role of the root in Arabic word recognition as a morphological processing unit and concluded that its effect is independent from both phonological and semantic effects (e.g., Boudelaa & Marslen-Wilson, 2000, 2001, 2011, 2015; Frost et al., 2000; Schluter, 2013)

It is important to note that across all the experiments of the current study, this comparable effect was obtained from Experiment 2B in which targets were morphologically more complex (prefixed nouns). When targets were prefixed nouns (Experiment 2B), +R−S competitors received significantly higher fixations than phonological competitors. By contrast, in Experiment 2A, when targets were complex nouns but non-affixed, phonological competitors received higher activation because (1) they shared the same onsets, (2) they shared at least 3 sounds with targets, and finally, they were more similar to targets in terms of the grammatical gender. In Experiment 2B, competitors in the two conditions did not share the same onsets with targets, however, they were matched in the overall phonological overlap and in the grammatical gender. As onsets are essential to mere phonological processing but not morphological processing, +R−S competitors received more fixation.

RT results showed that RTs to targets in all experimental conditions differed significantly from RTs in the baseline condition. No significant differences were found among the experimental conditions. Eyetracking seems to be more sensitive to lexical activation than RT data. A summary of predictions and fixation and RTs results for Experiments 2A is provided in Table 5.39. A "✓ symbol indicates the results fully supported the prediction; an ✗ indicates the results did not support the prediction and a "✓✗ indicates that the results partially supported the prediction.

	Target	**Competitor**	RTs
Experimental vs. Baseline	More looks to targets in the baseline than in the phonological, −R+S, +R+S, and +R−S due to the presence of related competitors in these conditions which is not the case in the baseline condition (✓).	Fewer looks to baseline “pseudo-competitor” than to competitors in all experimental conditions (✓).	Shorter RTs in the baseline condition than in all experimental conditions (✓).
+R+S vs. +R−S		Fewer looks to the +R−S competitors than to +R+S competitors (✓).	Shorter RTs in the +R−S condition (✗).
phonological vs. +R−S		Fewer looks to phonological competitors than to +R−S competitors (✓).	Shorter RTs in the phonological condition (✗).

Table 5.39: Predictions for Experiment 2B

All in all, the single-route connectionist model based on the results of Experiments 1 and 2A cannot accommodate the results obtained from Experiment 2B. The results of Experiments 1, 2A and 2B can only be accommodated by a parallel activation dual route model similar to previously proposed models that allows for both whole-word processing and morphological decomposition (e.g., Dahan et al., 2001; Deutsch et al., 1998; Giraudo & Grainger, 2000; Schreuder & Baayen, 1995). According to this proposed model, Arabic words are decomposed during the process of SWR and this is why we found significant effects of root-related conditions across Experiments 1, 2A and 2B. However, this effect is more pronounced in affixed words than in less complex forms of Arabic words (i.e., words formed from consonantal roots and word patterns without affixation). In the case of non-affixed words, words are processed via a whole-word route and a morphological decomposition route. So, words are processed as whole and via their morphemic units. The whole-word route and the morphological decomposition route compete for faster recognition, however, the whole-word route seems to be faster in the context of non-prefixed words. In the context of prefixed nouns, results showed different results. Root-related competitors were fixated more than other conditions and semantic transparency had no effect on fixations to +R+S versus +R−S conditions. This finding suggested that the whole-word route is faster in processing prefixed nouns. The morphological decomposition route is blind to semantic transparency. It process words and activates their morphological relatives regardless of their semantic transparency.

Although the morphological decomposition route processes words in parallel to the whole-word route, it becomes more efficient in the context of prefixed words. As the number of words starting with the same prefixes is large, the decompositional route is more effective and economical. Therefore, words are decomposed into their constituents and a small number of morphologically related words is activated. As the number of morphological relatives is considered small relative to all phonologically similar words in the lexicon, the effect of semantic transparency is less pronounced and differences between root-related words are not highly affected by the degree of semantic transparency. Words activated at both route undergo a selection. This model will discussed in more details in Chapter 6.

Chapter 6

General Discussion and Conclusion

This dissertation work addressed phonological, semantic and root activation in SWR in Arabic. In particular, root activation was the focus. Empirically, this work expands our understanding of many aspects of language processing. First, this is the first large scaled work to use the visual world paradigm to investigate SWR in Arabic. Second, to my knowledge, it was also the first to investigate the effects of phonological onset similarity and overall phonological overlap in Arabic. Third, this dissertation work was the first to investigate the effect of the Arabic consonantal root in two different noun contexts, namely, prefixed and non-prefixed words.

Closely tied to the methodological and empirical contributions, this dissertation also makes a theoretical contribution. Based on the results obtained from the three studies and findings from previous research, the current work proposes a model for SWR in Arabic. In this chapter, a summary of the findings is provided and discussed in relation to the three effects central to this dissertation. The chapter also introduces a proposed model for SWR in Arabic that can account for the results obtained from the current work. Finally, limitations and direction for future research are discussed.

6.1 Summary of Results

This dissertation has focused on the effect of the Arabic consonantal root in SWR and whether its effect is independent from phonological and semantic effects. To achieve this goal, three eyetracking experiments were conducted. Experiment 1 served as a foundation study to explore the nature of phonological, semantic and root activation. Results showed that proportional fixations to targets were affected by the presence of phonological, semantic and root competitors relative to the baseline unrelated pseudo-competitors. Competitors' fixations results showed that phonological competitors were fixated more than to the baseline pseudo-competitors. Fixations to phonological competitors was incremental and correlated with the phonological overlap between targets and competitors which happened to be an onset overlap in this study. Results also showed that semantic competitors were fixated more than to the baseline pseudo-competitors. Fixations to semantic competitors occurred at a later time point in the timecourse compared to the phonological competitors. With regard to the root condition, root competitors attracted the largest amount of fixations among all competitors. RTs results showed that only RTs to targets in the root condition differed significantly from RTs in the baseline condition.

Experiment 2A and 2B aimed to explore the effect of the Arabic root as a function of semantic transparency and phonological onset similarity. In Experiment 2A, results also showed that competitors in all experimental conditions were fixated more than to the baseline pseudo-competitors. Fixations to phonological competitors reflected the increased phonological overlap between targets and phonological competitors relative to Experiment 1 which was limited to the onset position. Pair-wise comparison between the root-related conditions showed that fixations to +R+S competitors were significantly higher than fixations to +R−S competitors despite the fact that they belong to the same root. This finding was taken as evidence for the effect of semantic transparency in SWR in Arabic. Pair-wise comparison between the phonological and +R−S conditions showed that fixations to the phonological competitors were higher than fixations to the +R−S competitors. This finding was attributed to the fact that many +R−S competitors were different from targets in terms of grammatical gender. RT results showed that only RTs in the phonological condition differed from RTs in the baseline condition. They also differed from RTs in the −R+S and +R−S conditions. The delay in RTs in the phonological condition can be attributed to the strong confusion created by the phonological similarity between targets and competitors and the absence of any semantic or morphological cues to resolve that confusion. It can also be attributed to the similarity with targets in terms of gender. In general, the results of Experiment 2A provided support for the effect of semantic transparency in SWR in the context of non-affixed nouns. It was also at odds with obligatory decomposition models of complex word recognition. The results of this experiments were explained within a single-route distributed connectionist model and within a dual-route parallel activation model.

Experiment 2B used the same design, procedures and conditions of Experiment 2A, however, stimuli were seven prefixed nouns. Competitors were non-prefixed nouns. Therefore, none of the competitors matched targets in the phonological onset. The assumption was that if the root is a processing unit in SWR in Arabic, then it should not be largely affected by the dissimilarity of onsets. Phonological competitors, on the other hand, should be affected by the dissimilarity of onsets as onsets have been found to play an important role in lexical activation. In addition, this experiment aimed to explore the effect of semantic transparency in root activation in the context of more complex words. Results showed that fixations proportions to targets were affected by the presence of competitors in all condition relative to the baseline condition. Competitors' fixations results showed that fixations to the phonological competitors did not significantly differ from fixation to the baseline pseudo competitors. Although differences in the slopes were captured by the polynomial terms, this finding highlights the importance of onset similarity in phonological activation. Results also showed significant effects of semantic association, −R+S were fixated more than the baseline pseudo-competitors. The effect of semantic association was found significant in both Experiments 2A and 2B regardless of the morphological complexity of targets. No significant difference was found between the overall means of fixations to competitors in the +R+S and +R−S conditions. Only one difference was found between the slopes of these conditions captured by the cubic terms. This finding indicates that in the context of prefixed Arabic nouns, semantic transparency plays no role (or a very minimal role) in morphological activation of root relatives. This finding provided support for previous priming studies that have found comparable priming effects for root related words regardless of semantic transparency (Boudelaa & Marslen-Wilson, 2000, 2015), however, the current work limits this finding to prefixed nouns as semantic transparency was found to play a significant role in the context of non-affixed nouns.

Taken together, the results of these experiments highlight the importance of the phonological, semantic and root effect in SWR in Arabic. The results of these experiments can be accommodated by a dual route model featuring two parallel processing pathways: a whole-word route and a morphological decomposition route. The following sections summarize the main findings of this research in relation to the three variables (phonological, semantic and morphological variables) that were central to this dissertation.

6.1.1 Phonological activation

The results confirmed the importance of phonological onset in SWR (e.g., Alamri & Zamuner, 2015; Allopenna et al., 1998; Magnuson et al., 1999; Marslen-Wilson & Zwitserlood, 1989; McMurray et al., 2003; Radeau et al., 1995; Slowiaczek et al., 1987). Results of Experiment 1 showed that fixations to competitors reflected the phonological similarity between the spoken words (targets) and competitors which happened to be the onsets (first two or three segments). In Experiment 2A, the amount of phonological similarity between targets and phonological competitors was increased. Fixations to phonological competitors were higher and more persistent than in Experiment 1. In Experiment 2B, phonological competitors shared three or more segments with targets including at least two of the targets root consonants, however, they did not share the same onsets. Fixation results showed that fixations to phonological competitors were decreased. However, phonological competitors were fixated to more than the baseline unrelated items. This finding is in line with previous eyetracking studies that have found that phonological competitors are available for processing even after time at which they acoustically mismatch with a spoken input (Allopenna et al., 1998; Dahan, 2010; Dahan & Gaskell, 2007).

6.1.2 Semantic activation

Semantic activation was reliable across the three experiments. Competitors that were semantically associated with targets were fixated more than baseline unrelated pseudo-competitors. This finding provide support to previous studies that have obtained similar results from the priming paradigm (e.g., Collins & Loftus, 1975; Hutchison, 2003) and the visual word paradigm with eyetracking (Apfelbaum et al., 2011; Huettig & Altmann, 2005; Mirman & Magnuson, 2009; Yee & Sedivy, 2006). With regard to the timecourse of semantic activation, fixations to semantically related competitors was found to increase around 400 ms. after word onset. This is considered an early access to semantic information. This is consistent with previous finding that have found an early effect of semantic features (e.g., Huettig & Altmann, 2005; Yee & Sedivy, 2006). The relatively short delay in fixation to the semantic competitor is expected since access to some phonological representations of targets is necessary for semantic effect to occur (Yee & Sedivy, 2006). That is, shortly after words are phonological access starts, semantic information becomes available and semantic effect occurs.

6.1.3 Root activation

Root activation was significantly higher than phonological and semantic activation in Experiment 1. Previous research found strong effects of the consonantal root in SWR in Arabic (Boudelaa & Marslen-Wilson, 2000, 2015; Gwilliams & Marantz, 2015), Hebrew (e.g., Deutsch et al., 1998; Frost et al., 1997) and Maltese (e.g., Ussishkin et al., 2015). Similarly, reading studies using the eyetracking methodology have reported more gazes and longer fixation durations to morphologically related words (Andrews et al., 2004; Paterson et al., 2011). In order to explore whether the strong activation of root-related competitors found in Experiment 1 was a result of the combining effects phonology and semantics or a result of morphological processing, Experiments 2A and 2B were designed to isolate the effect of root-related competitors as a function of semantic transparency and phonological similarity in the context of non-affixed words (Experiment 2A) and in the context of prefixed words (Experiment 2B). In these two experiments, two sets of root-related words were selected: semantically transparent root-related words (+R+S) and semantically opaque root-related (+R−S). In Experiment 2A, both +R+S and +R−S competitors were fixated more than to the baseline unrelated words. However, compared to each other, results showed that +R+S competitors were fixated more than to +R−S competitors suggesting that semantic transparency plays an important role in the activation of morphologically related words in the context of non-prefixed words. This finding was in line with previous research underscoring the effect of semantic transparency in complex word recognition (e.g., Giraudo & Grainger, 2000; Gonnerman et al., 2007; Kielar & Joanisse, 2010, 2011; Longtin et al., 2003; Marslen-Wilson et al., 1994; Plaut & Gonnerman, 2000). This finding was, however, at odds with previous research that found comparable priming effects of root-related words regardless of semantic transparency (Boudelaa & Marslen-Wilson, 2000, 2015). Experiment 2A results also provided data against the obligatory decomposition account of SWR in Arabic proposed by Boudelaa (2014) for word recognition in Arabic as this cannot account for the significantly effect of semantic transparency in the context of non-prefixed nouns.

Comparing the +R+S and +R−S conditions in the context of prefixed words (Experiment 2B), the only difference that was found was captured by the cubic terms which is not very informative in the absence of other differences. This indicates that root-related words are activated to similar degrees in the context of prefixed words in Arabic and that semantic transparency does not play any significant role in complex word recognition in the context of prefixed words. This finding supported the previous findings by (Boudelaa & Marslen-Wilson, 2000, 2015), however, this finding is limited to prefixed words according to the results of the current work.

Finally, with regard to the effect of phonological similarity on the activation of root-related words, results showed that phonological competitors were fixated more than to +R−S competitors in Experiment 2A. +R−S competitors were expected to receive higher activation due to the fact they shared the same onsets and the same consonantal root. However, phonological competitors were fixated to more. This was attributed to the fact that more phonological competitors matched targets in terms of grammatical gender than +R−S competitors. This explanation is consistent with previous findings that have found nouns sharing the same gender activate each other (e.g., Cubelli et al., 2011; Duffy & Keir, 2004). In Experiment 2B, results of comparing fixations +R−S competitors and phonological competitors revealed that phonological competitors were more affected by the mismatch with targets in the onset position. By contrast, +R−S competitors were not affected by mismatch with targets in the onset position. This finding provides support to the claim that the root is an independent processing unit (Boudelaa & Marslen-Wilson, 2000, 2015; Gwilliams & Marantz, 2015).

The results of Experiment 2A which was in the context of non-prefixed words can be accommodated within a single-route interactive activation model similar to the model suggested by Gonnerman et al. (2007) which features phonological, orthographic and semantic processing units as well as an interlevel unit that computes the probabilistic relationships between words in terms of phonology, semantic (and orthographic) codes. In addition, this interlevel is sensitive to grammatical features such as grammatical gender. This model can account for the graded effect of root activation as a function of semantic transparency. It can also account for the higher activation found for phonological competitors relative to +R−S competitors as the interlevel weights given to +R−S competitors were lower due to gender mismatch with targets.

This model that was suggested based on the results of Experiment 2A failed to account for the comparable activation of root-related competitors regardless of semantic transparency obtained from Experiment 2B in the context of prefixed words. Therefore, I come to the conclusion that the only model that can accommodate the results of the three experiments of the current work is a model that allows both whole-word processing and morphological decomposition. Therefore, I propose a dual route parallel activation model that features a whole-word route and a morphological decomposition route. This model is explained below.

6.2 Proposed model for SWR in Arabic

A discussed earlier, the results obtained from Experiments 1 and 2A can be explained within a single route non-decompositional route. However, the results obtained from Experiment 2B regarding the comparable activation of semantically transparent and semantically opaque root-related words, as well as the limited effect of onset mismatch on root-related words' activation made it less likely that non-decompositional models can account for word recognition in Arabic. Therefore, a dual route model that features whole-word and morphological decomposition pathways is proposed. This model is a combination of two previous models: a distributed connectionist model proposed by Gonnerman et al. (2007) and a dual route model similar to the models proposed by Baayen et al. (1997); Schreuder and

Baayen (1997). The model consists of two routes: a whole-word route and a morphological decomposition route (see Figure 6.1). The whole-word route functions in a distributed connectionist fashion. Circles in the whole-word route represents the phonological, semantic and interlevel processing units. The interlevel unit computes the phonological, semantic and grammatical relationships among words and assign weights on these connections (the lines). The activation of words is dependent on the weights of the connections between the input and the mental representations of words in the mental lexicon.

The morphological decomposition route functions in parallel to the whole-word route. Semantic features are not available to morphological decomposition. It used roots as processing units (and probably patterns and affixes) and hence words belonging to the same root are activated regardless of their semantic features. The two routes compete for faster recognition. Arabic non-prefixed words are more likely to be processed faster by the whole-word route. As semantic and grammatical features of words are available to this route, the effects of semantic transparency and grammatical features play an important role in lexical activation. Prefixed words, on the other hand, are more likely to be processed faster by the morphological decomposition route as it is able to extract the morphemic constituents of words. The whole-word route is slower in the context of prefixed words due to the large number of words starting with the same prefix in Arabic. For instance, almost every consonantal root in Arabic can interleave with a pattern with the prefix [ma] which indicates the place of an action. This huge number of candidates slows down the recognition via the whole-word route. The morphological decomposition route by contrast is more able to extract the morphemic constituents of words and activate limited number of words related to these constituents.

This model can accommodate the results of the current study. The non-prefixed nouns in Experiment 2A were processed by the whole-word route and hence we found that there was an effect of semantic transparency. This effect was absent in the context of prefixed nouns which may indicate that the prefixed nouns in Experiment 2B were processed by the decompositional route. Therefore, no differences were found in Experiment 2B in fixations or RTs between semantically transparent and semantically opaque root-related words. Both types of root-related words were not also affected by the mismatch with targets at the onset position.

The model can also account for the previous results that have found similar priming activation for root-related words regardless of semantic transparency (Boudelaa & Marslen-Wilson, 2000, 2015). This model can be a point of departure for more sophisticated model that can account for other variables that were not investigated in the current work.

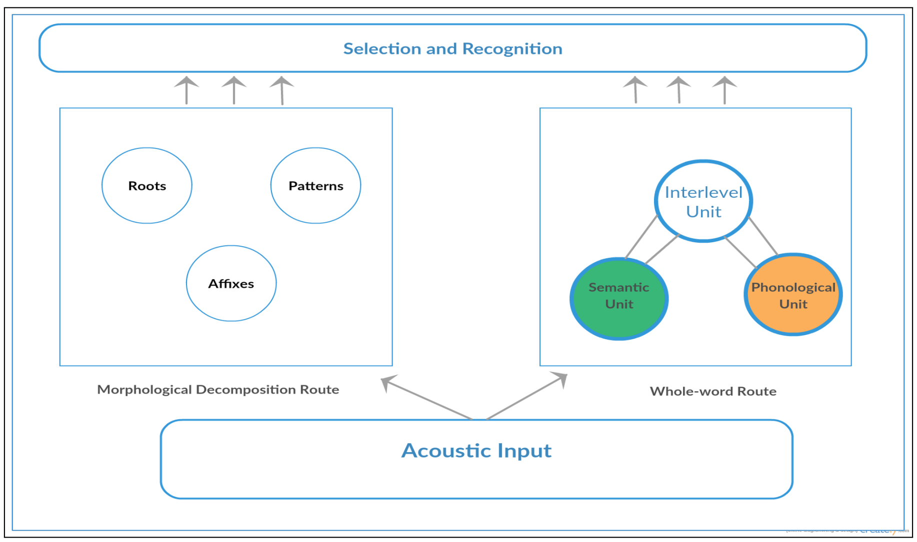

Figure 6.1: A dual route model for SWR in Arabic.

To sum up, the current work has found that phonology, semantics and morphology (root) play important roles in SWR in Arabic. The presence of phonologically, semantically, or root related competitors affected the amount of fixations to targets relative to unrelated items. Fixations to competitors were graded and corresponded to the different amounts of phonological, semantic and morphological overlap between targets and competitors. Semantic transparency has been found to play an important role in morphological activation in the context of non-prefixed nouns but not in the context of prefixed nouns. Phonological onset was also found to be essential to phonological and root activation in SWR in Arabic. The results of this work also highlight the importance of the Arabic consonantal root as an independent processing unit in lexical access in SWR in Arabic that is separable from phonological and semantic units of processing. Finally, the results of this work provided support to models of SWR that feature both whole-word processing as well as morphological decomposition (e.g. Baayen et al., 1997; Giraudo & Grainger, 2000; Schreuder & Baayen, 1997). They also provide support to the morpheme-based theory of Arabic morphology (McCarthy, 1979, 1981). Finally, the current work distinguishes between two types of nouns, namely, prefixed and non-prefixed nouns. Non-prefixed nouns were found to be more likely to be processed as whole words whereas prefixed nouns were found to be more likely to be processed via morphological decomposition.

6.3 Limitations and future research

One of the limitations of the current dissertation work is that in Experiment 2, grammatical gender was not controlled for which may have been the reason for some surprising results in targets and competitors' fixations. Moreover, the results of the current work are limited to Saudi Arabic and may not generalizable to other Arabic dialects. In addition, the results are limited to the nominal system of Arabic and may not be generalizable to the verbal system.

Some important implications for future research on word recognition in Arabic can be drawn from this dissertation work. First, this study suggests that the complexity of Arabic words can be a predictor of they way they are processed and recognized. Previous research on word recognition in Arabic (Boudelaa & Marslen-Wilson, 2000, 2015) used stimuli that were a mix of prefixed, suffixed and non-affixed words. The results of the current work have indicated many differences between the processing of prefixed and non-prefixed nouns. Therefore, it is highly recommended that future research control for the complexity of words when designing empirical research. Second, the visual world paradigm is a very useful methodology in investigating SWR in Arabic despite the non-linear internal structure of Arabic words. Therefore, utilizing this methodology in investigating spoken and visual word recognition in Arabic is encouraged.

As for future directions, it would be valuable to replicate this work using a slightly different design in which two competitors are presented with each target in the same display. For instance, a target appears with a phonological competitor, a root competitor and one unrelated item. This way, we can see which of the two competitors would attract more looking. Another valuable study would be to investigate the effect of semantic transparency in root activation using competitors with graded semantic association with targets. That is, using three or more conditions with competitors that have graded semantic transparency to targets (e.g., transparent, moderate and opaque root-related words). Only by doing this, we can be more confident that semantic transparency has graded effects that reflect semantic relatedness. The effects of neighbourhood density and root productivity are also important directions for future research as, to my knowledge, very little research (though see Wray, 2016) has investigated their effect in SWR. Another important direction is to investigate the effect of the Arabic consonantal root in children and illiterate participants. This will provide more convincing evidence that the effect of the root is not a converging effect of phonological, semantic and orthographic similarities. Finally, extending the investigation of root activation to other understudied Semitic languages such as Amharic and Tigrinya spoken in Ethiopia and Eritrea would be of a great importance in understanding the nature morphological processing in Semitic languages.

APPENDICES

Appendix A

Language Questionnaire

Language History Questionnaire

uOttawa

Université d'Ottawa
Faculté des arts
Linguistique

University of Ottawa
Faculty of Arts
Linguistics

Contact Information:
Name: ___________________________ Email:___________________
Telephone: ________________ Today's Date ____________________

Please answer the following questions to the best of your knowledge.

Have you ever had any kind of hearing impairment? If so, please describe it.

Have you ever had any kind of reading impairment? If so, please describe it.

PART A

1. Date of birth:
2. Sex (circle one): Male / Female
3. Education (degree obtained or school level attended):

4. (a). Country of origin:
   (b). Country of residence:

5. If 4(a) and 4(b) are the same, how long have you lived in a foreign country where your second language is spoken? If 4(a) and 4(b) are different, how long have you been in the country of your current residence?

6. What is your native language? (If you grew up with more than one language since birth, please specify)

7. Do you speak a second language?
   ____YES my second language is __________.
   ____NO (If you answered NO, you need not continue this form)

613-562-5286
613-562-5141
70 Laurier E.
Ottawa ON K1N 6N5 Canada
www.uOttawa.ca

uOttawa

Université d'Ottawa
Faculté des arts
Linguistique

University of Ottawa
Faculty of Arts
Linguistics

613-562-5286
613-562-5141
70 Laurier E.
Ottawa ON K1N 6N5 Canada
www.uOttawa.ca

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

At home ____________
At school ____________
After arriving in the second language speaking country ___________________

9. How did you learn your second language up to this point? (please check all that apply)
(Mainly Mostly Occasionally) through formal classroom instruction.
(Mainly Mostly Occasionally) through interacting with people.
A mixture of both, but (more classroom - more interaction - equally both).
Other (please specify): ______________________________________.

10. List all foreign languages you know (with the age at which you were first exposed to that language) in order of most proficient to least proficient. Rate your ability on the following aspects in each language. Please rate according to the following scale (write down the number in the table):

very poor	poor	fair	functional	good	very good	native-like
1	2	3	4	5	6	7

Language	Age 1st exposed	Reading proficiency	Writing proficiency	Speaking fluency	Listening ability

PART B
11. What language do you usually speak to your mother at home? (If not applicable for any reason, write N/A)

12. What language do you usually speak to your father at home? (If not applicable for any reason, write N/A)

13. What languages can your parents speak fluently? (If not applicable for any reason, write N/A)

Mother: ____

Father: ____

uOttawa

Université d'Ottawa
Faculté des arts
Linguistique

University of Ottawa
Faculty of Arts
Linguistics

613-562-5286
613-562-5141
70 Laurier E.
Ottawa ON K1N 6N5 Canada
www.uOttawa.ca

14. What language or languages do your parents usually speak to each other at home? (If not applicable for any reason, write N/A)

15. Write down the name of the language in which your received instruction in school, for each schooling level:

Primary/Elementary School ____________________________
Secondary/Middle School ____________________________
High School ____________________________
College/University ____________________________

16. Estimate, in terms of percentages, how often you use your native language and other languages per day (in all daily activities combined):

Native language ________%
Seconds language ________%
Other languages ________% (specify: ______________________)
(Total should equal 100%)

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

Appendix B

Other pair-wise comparison tables and plots Chapter 5

B.1 Experiment 2A

	Estimate	Std. Error	t-value	p-value
(Intercept)	0.326	0.484	0.675	0.500
Linear	15.278	2.498	6.115	0.000
Quadratic	6.541	1.853	3.531	0.000
Cubic	-5.189	1.391	-3.730	0.000
Condition	0.598	0.587	1.019	0.308
Linear:Condition	-1.066	1.098	-0.971	0.332
Quadratic:Condition	-4.898	1.057	-4.634	0.000
Cubic:Condition	2.589	0.991	2.612	0.009

Table B.1: Target fixation: empirical logit GCA results for Phonological (the reference condition) versus -R+S

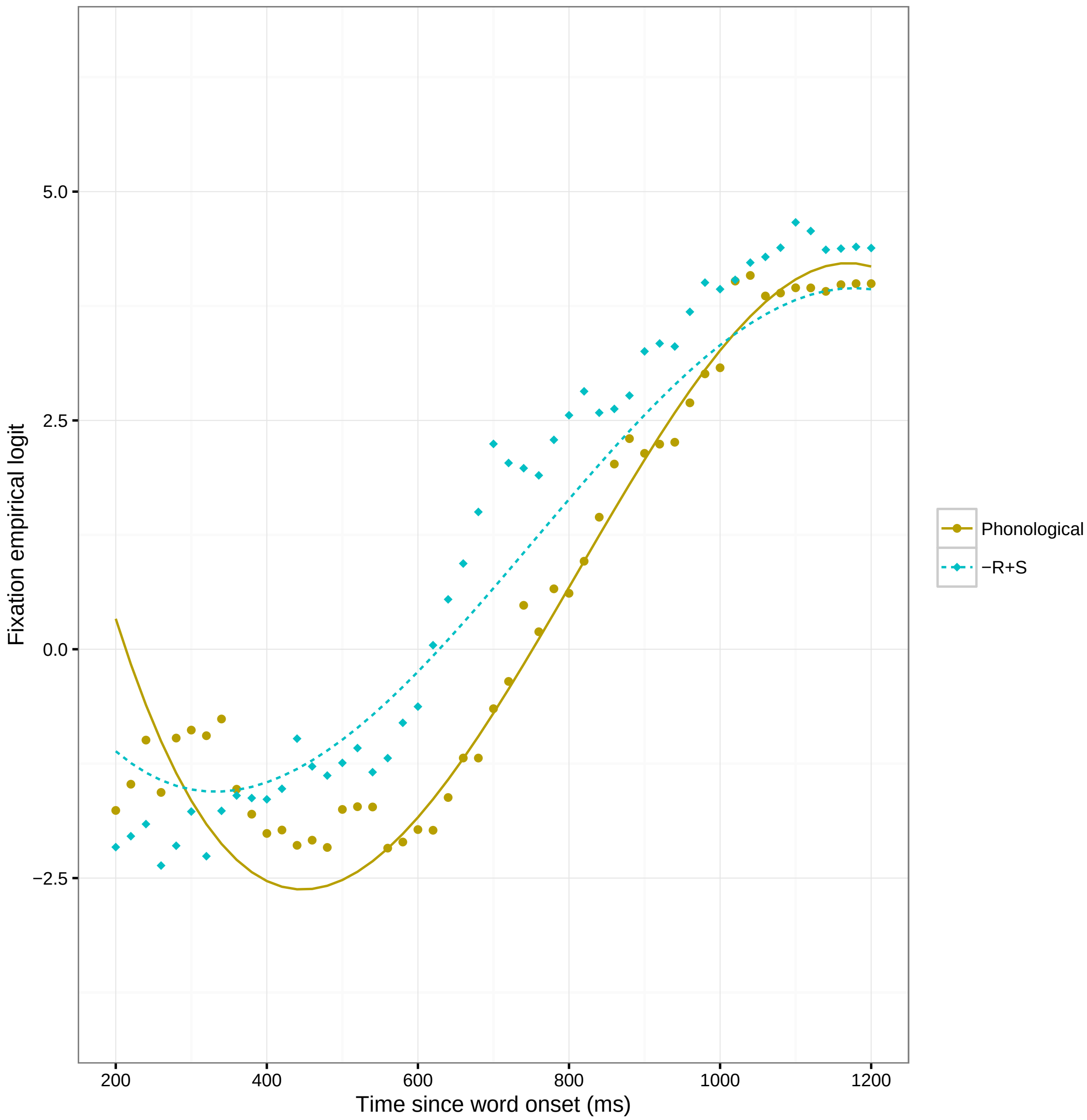

Figure B.1: Target fixation: observed data (symbols) and GCA model fits for Phonological versus -R+S

	Estimate	Std. Error	t-value	p-value
(Intercept)	-2.838	0.265	-10.719	0.000
Linear	-10.764	2.217	-4.856	0.000
Quadratic	-3.087	1.755	-1.758	0.079
Cubic	3.500	1.435	2.439	0.015
Condition	-0.452	0.417	-1.086	0.278
Linear:Condition	6.067	1.067	5.684	0.000
Quadratic:Condition	0.561	1.027	0.546	0.585
Cubic:Condition	-2.045	0.990	-2.065	0.039

Table B.2: Competitor fixation: Empirical logit GCA results for Phonological (the reference condition) versus -R+S

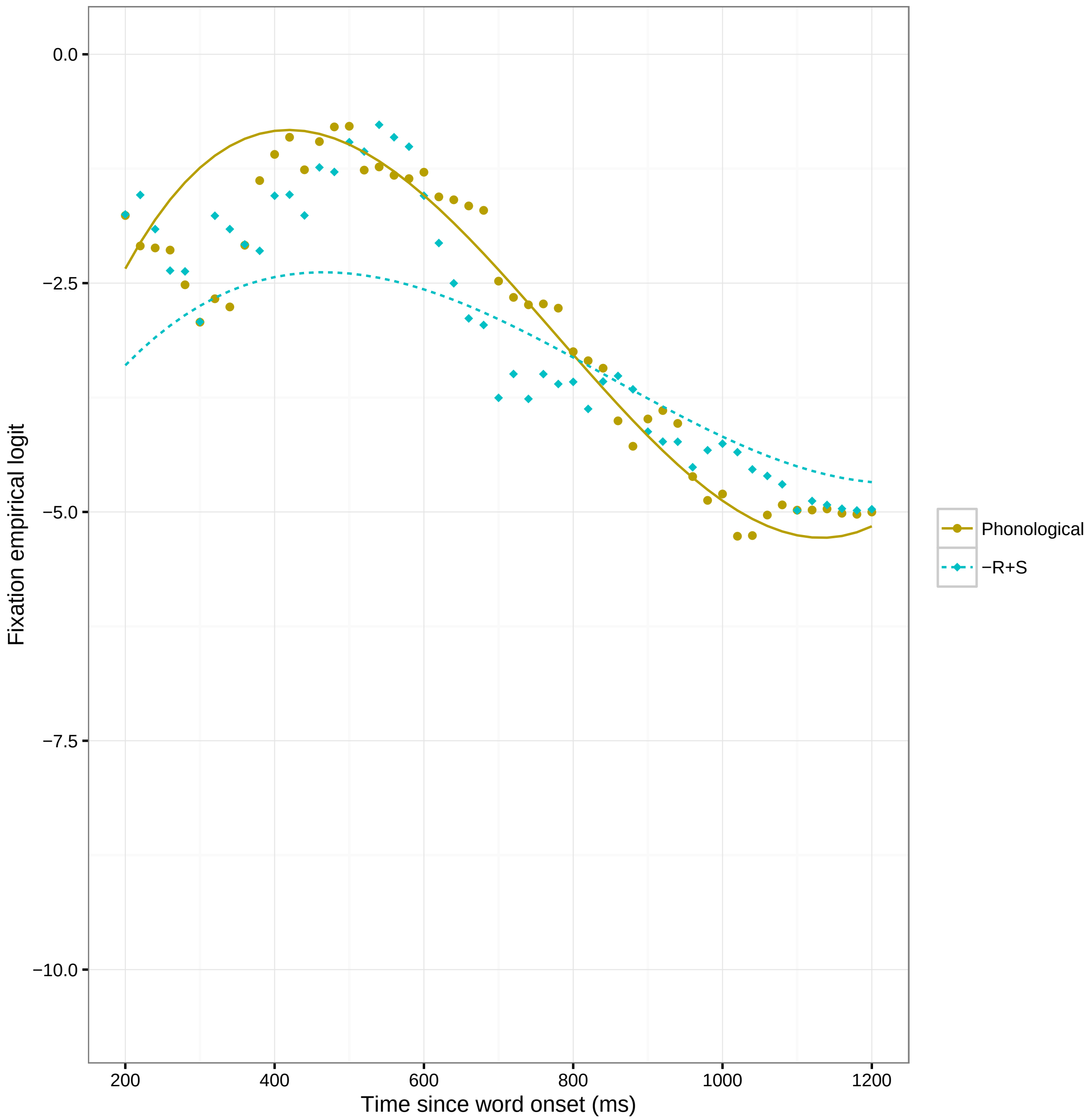

Figure B.2: Competitor fixation: observed data (symbols) and GCA model fits for Phonological versus -R+S

	Estimate	Std. Error	t-value	p-value
(Intercept)	0.563	0.487	1.158	0.247
Linear	11.297	2.118	5.335	0.000
Quadratic	8.505	2.005	4.242	0.000
Cubic	-4.627	1.689	-2.740	0.006
Condition	-0.554	0.780	-0.710	0.477
Linear:Condition	9.553	1.113	8.583	0.000
Quadratic:Condition	-11.505	1.100	-10.460	0.000
Cubic:Condition	3.634	1.015	3.582	0.000

Table B.3: Target fixation: empirical logit GCA results for Phonological (the reference condition) versus +R+S

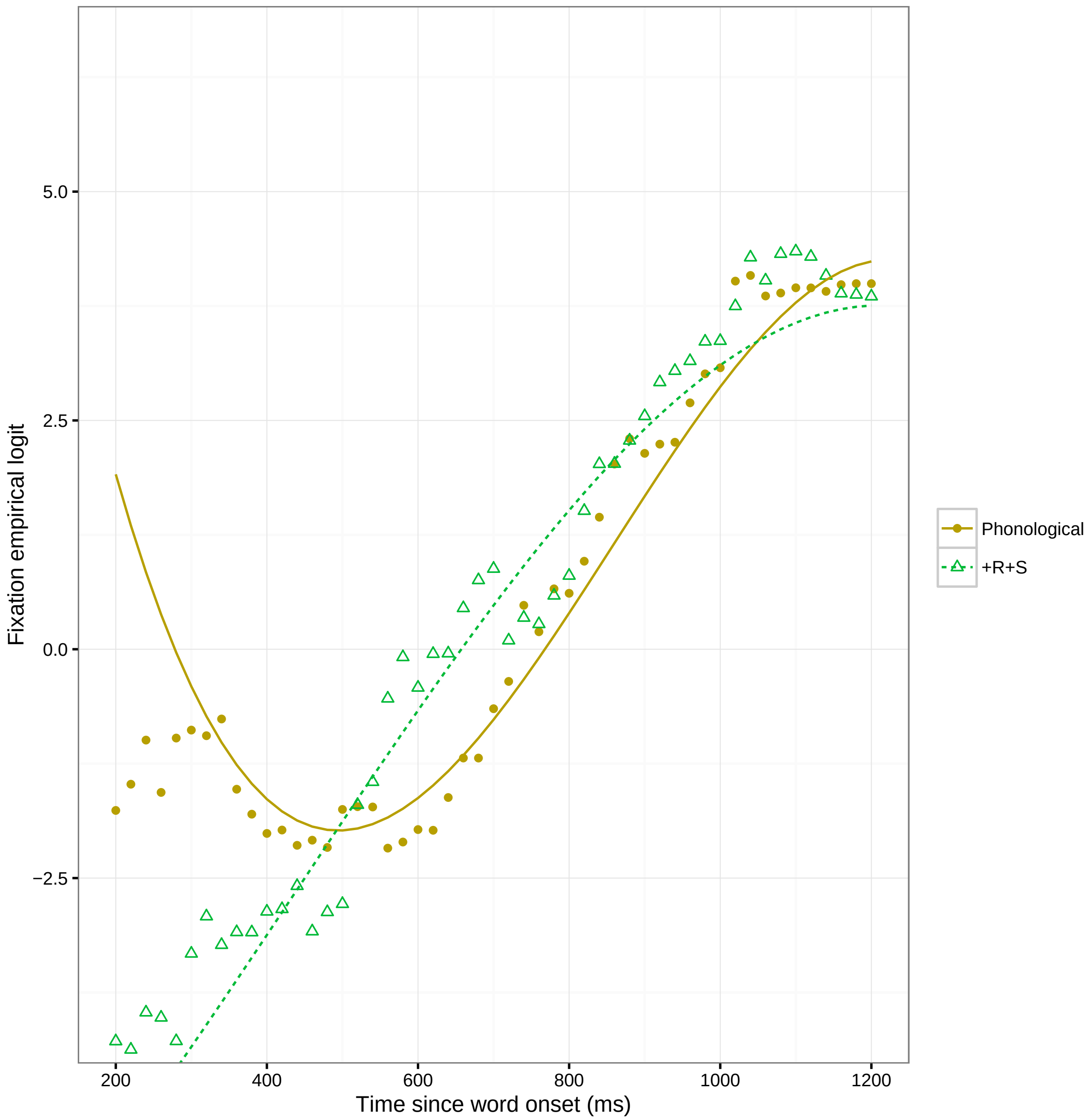

Figure B.3: Target fixation: observed data (symbols) and GCA model fits for Phonological versus +R+S

	Estimate	Std. Error	t-value	p-value
(Intercept)	-2.957	0.430	-6.875	0.000
Linear	-7.848	2.259	-3.475	0.001
Quadratic	-4.176	2.061	-2.026	0.043
Cubic	2.485	1.687	1.473	0.141
Condition	1.082	0.640	1.691	0.091
Linear:Condition	0.866	1.021	0.848	0.396
Quadratic:Condition	2.900	1.012	2.866	0.004
Cubic:Condition	-4.752	0.950	-5.001	0.000

Table B.4: Competitor fixation: Empirical logit GCA results for Phonological (the reference condition) versus +R+S

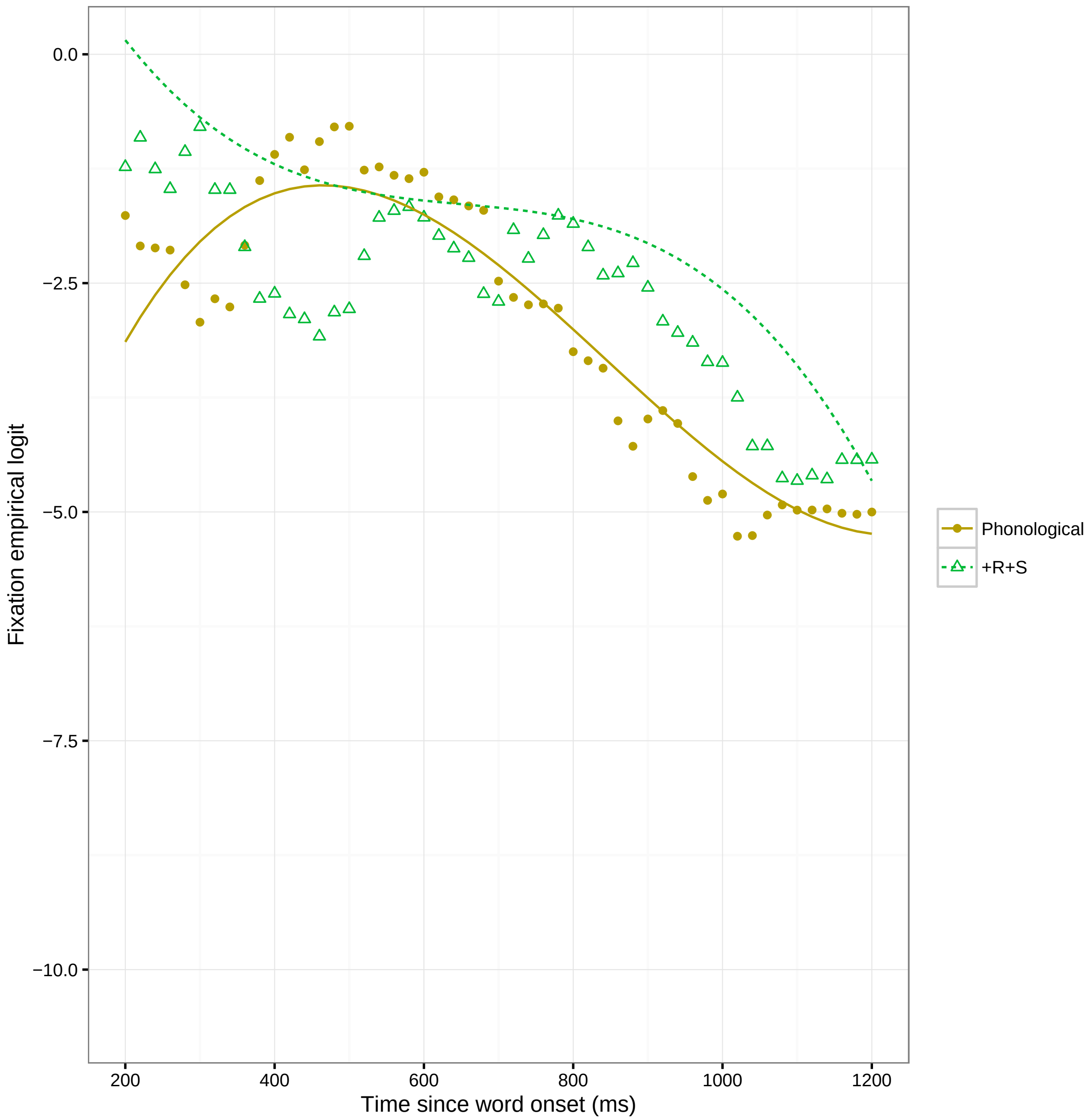

Figure B.4: Competitor fixation: observed data (symbols) and GCA model fits for Phonological versus +R+S

	Estimate	Std. Error	t-value	p-value
(Intercept)	-0.108	0.597	-0.180	0.857
Linear	13.116	2.562	5.120	0.000
Quadratic	1.758	1.708	1.029	0.304
Cubic	0.013	1.317	0.010	0.992
Condition	0.927	0.806	1.150	0.250
Linear:Condition	3.880	1.098	3.535	0.000
Quadratic:Condition	-1.700	1.043	-1.630	0.103
Cubic:Condition	-3.747	0.990	-3.785	0.000

Table B.5: Target fixation: empirical logit GCA results for +R+S (the reference condition) versus -R+S

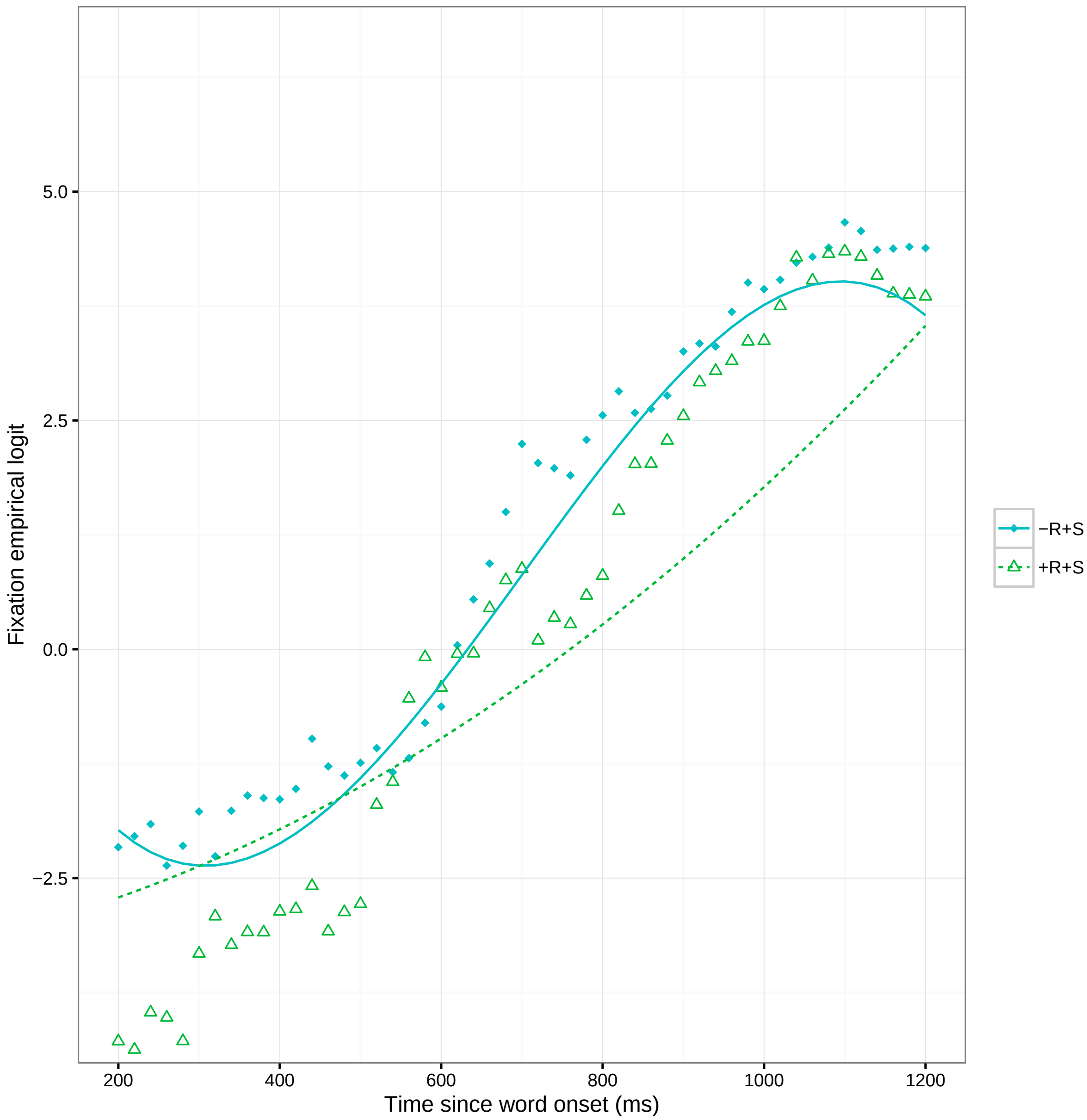

Figure B.5: Target fixation: observed data (symbols) and GCA model fits for +R+S versus -R+S

	Estimate	Std. Error	t-value	p-value
(Intercept)	-1.831	0.588	-3.111	0.002
Linear	-5.832	2.334	-2.499	0.012
Quadratic	-1.896	1.696	-1.118	0.263
Cubic	-3.657	1.509	-2.423	0.015
Condition	-1.357	0.713	-1.902	0.057
Linear:Condition	0.281	1.094	0.257	0.797
Quadratic:Condition	0.156	1.040	0.150	0.881
Cubic:Condition	6.735	1.005	6.702	0.000

Table B.6: Competitor fixation: Empirical logit GCA results for +R+S (the reference condition) versus -R+S

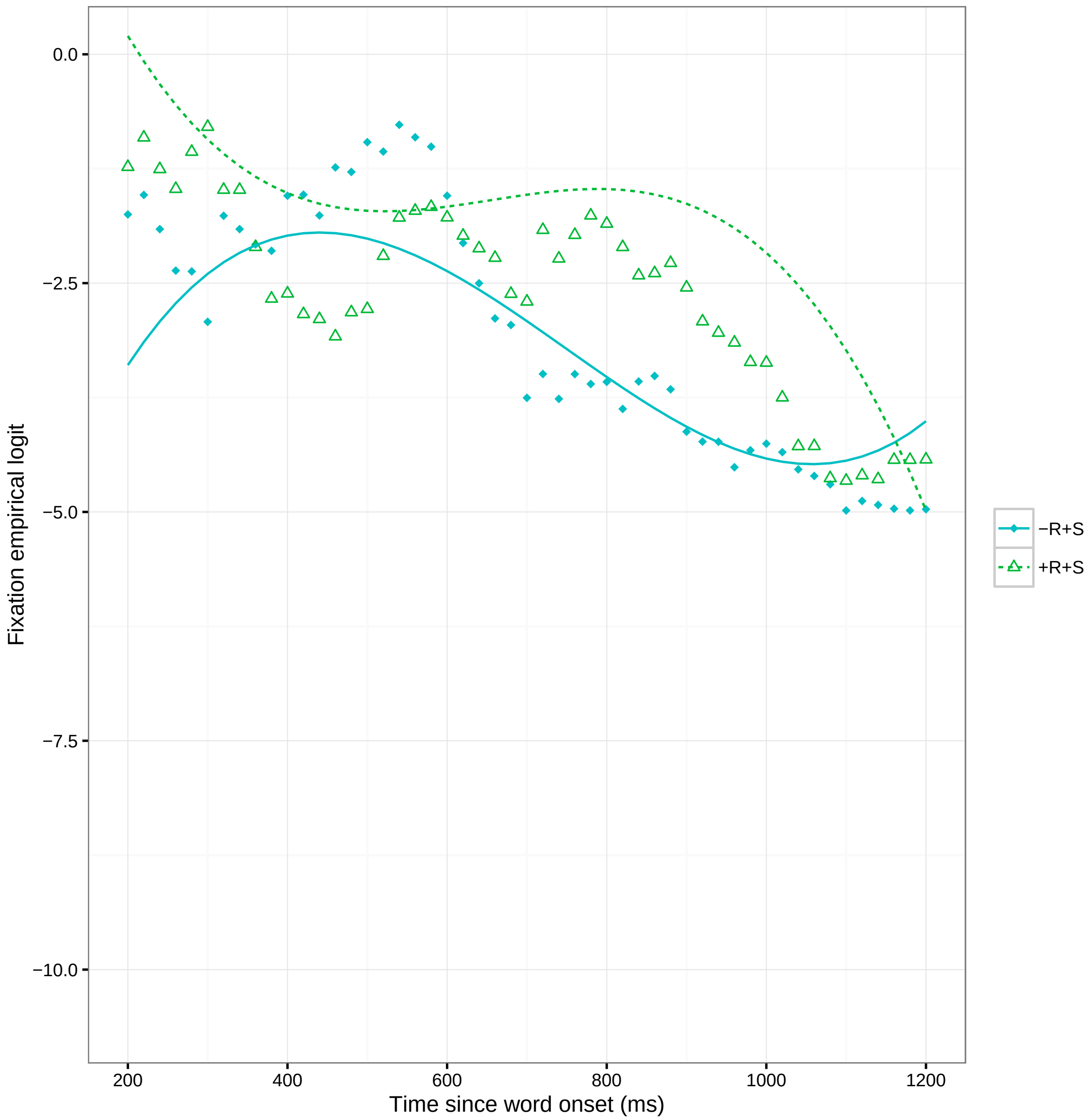

Figure B.6: Competitor fixation: observed data (symbols) and GCA model fits for -R+S versus +R+S

	Estimate	Std. Error	t-value	p-value
(Intercept)	1.081	0.492	2.198	0.028
Linear	17.264	2.071	8.337	0.000
Quadratic	-3.187	1.887	-1.689	0.091
Cubic	-1.918	1.406	-1.364	0.173
Condition	-0.294	0.661	-0.444	0.657
Linear:Condition	-2.349	1.165	-2.016	0.044
Quadratic:Condition	5.567	1.122	4.963	0.000
Cubic:Condition	-1.851	1.085	-1.706	0.088

Table B.7: Target fixation: empirical logit GCA results for +R-S (the reference condition) versus -R+S

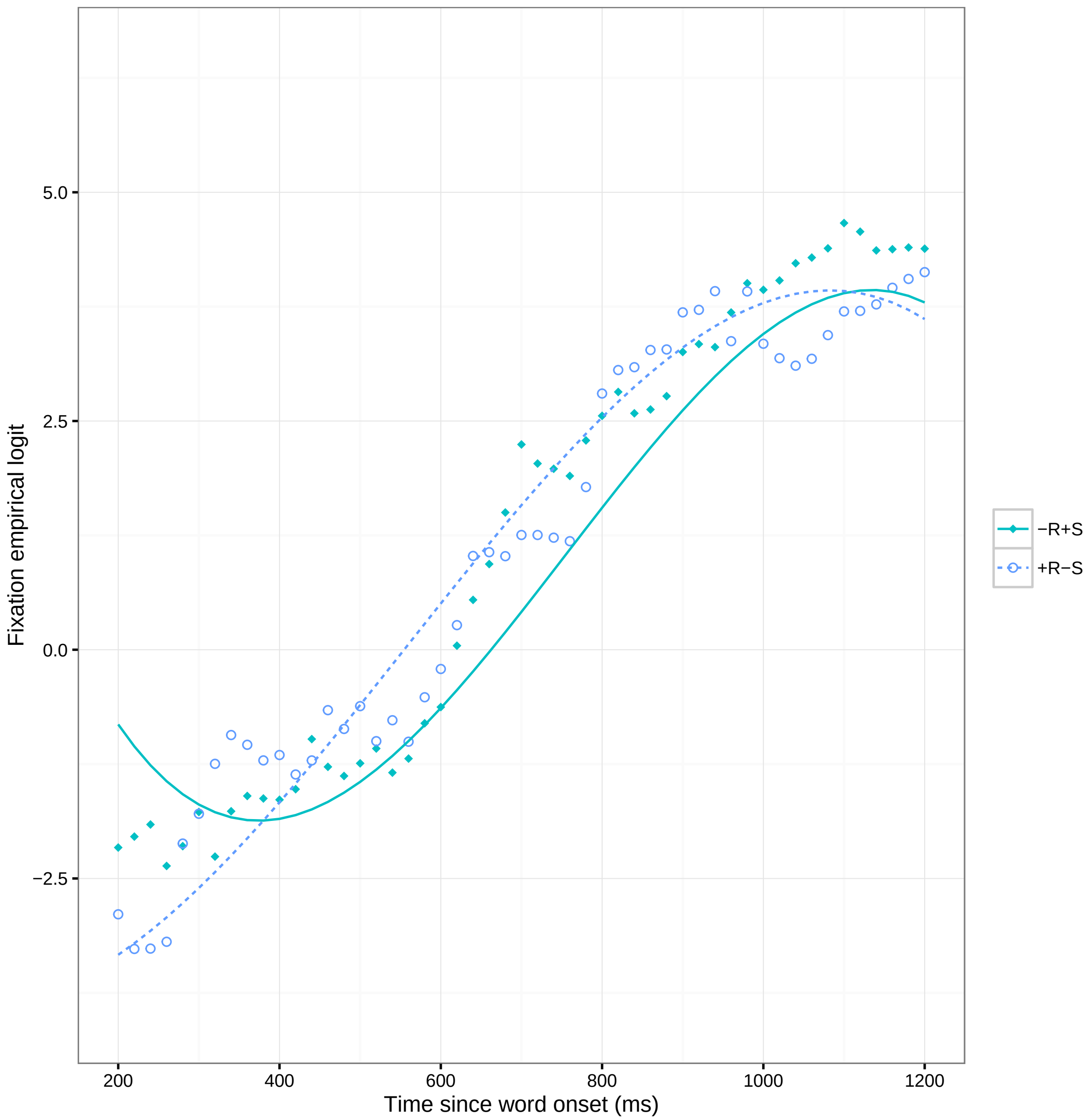

Figure B.7: Target fixation: observed data (symbols) and GCA model fits for +R-S versus -R+S

B.2 Experiment 2B

	Estimate	Std. Error	t-value	p-value
(Intercept)	1.154	0.459	2.513	0.012
Linear	19.334	2.463	7.848	0.000
Quadratic	0.399	2.234	0.178	0.858
Cubic	-5.117	1.476	-3.467	0.001
Condition	0.164	0.622	0.263	0.793
Linear:Condition	-3.779	0.957	-3.951	0.000
Quadratic:Condition	1.037	0.879	1.180	0.238
Cubic:Condition	0.342	0.851	0.402	0.688

Table B.8: Target fixation: empirical logit GCA results for Phonological (the reference condition) versus -R+S

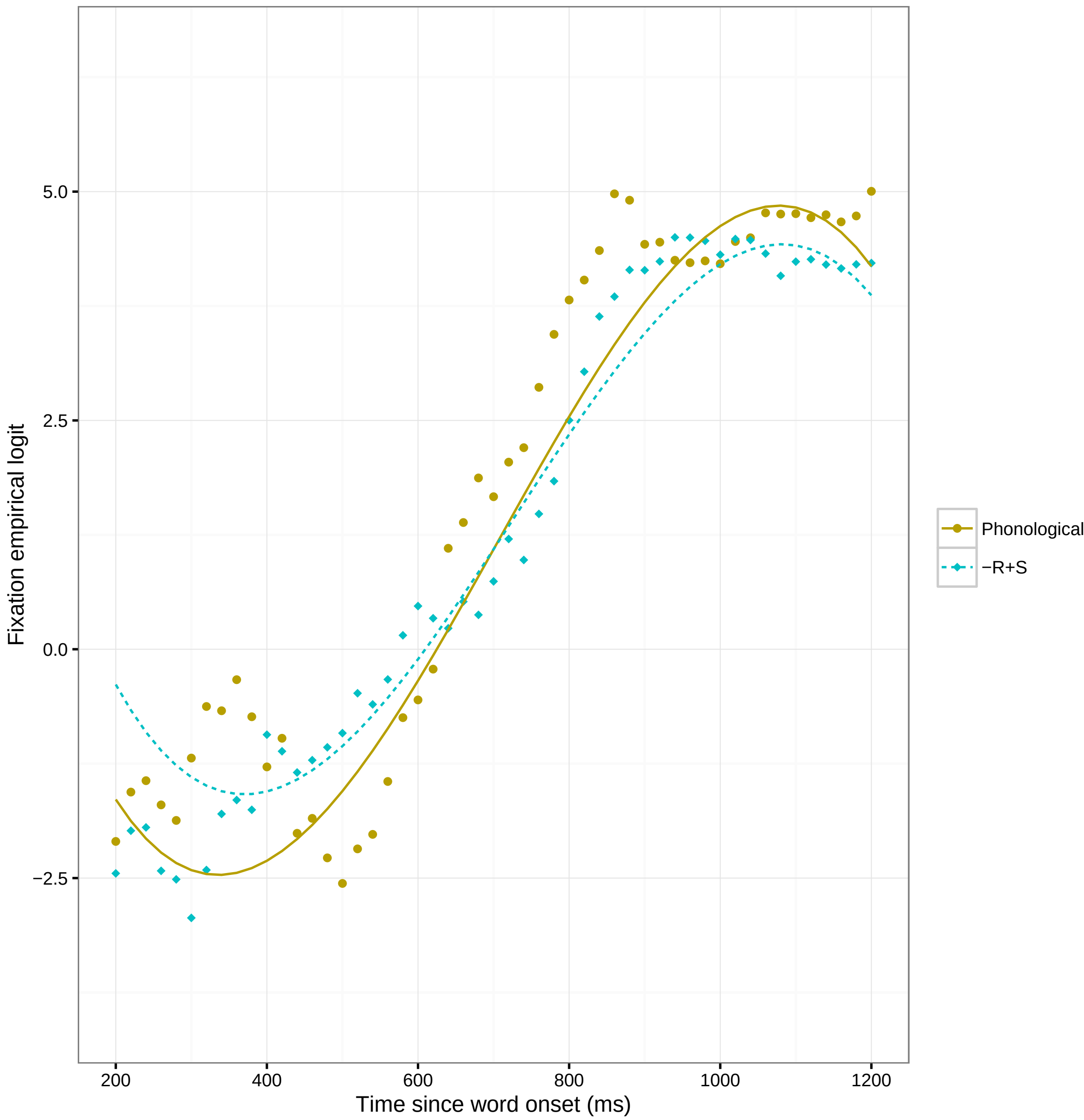

Figure B.8: Target fixation: observed data (symbols) and GCA model fits for Phonological versus -R+S

	Estimate	Std. Error	t-value	p-value
(Intercept)	-3.999	0.174	-22.990	0.000
Linear	-7.503	1.366	-5.494	0.000
Quadratic	1.163	1.803	0.645	0.519
Cubic	1.943	1.302	1.493	0.135
Condition	0.401	0.344	1.165	0.244
Linear:Condition	4.982	0.801	6.220	0.000
Quadratic:Condition	-5.053	0.745	-6.787	0.000
Cubic:Condition	-0.365	0.721	-0.506	0.613

Table B.9: Competitor fixation: Empirical logit GCA results for Phonological (the reference condition) versus -R+S

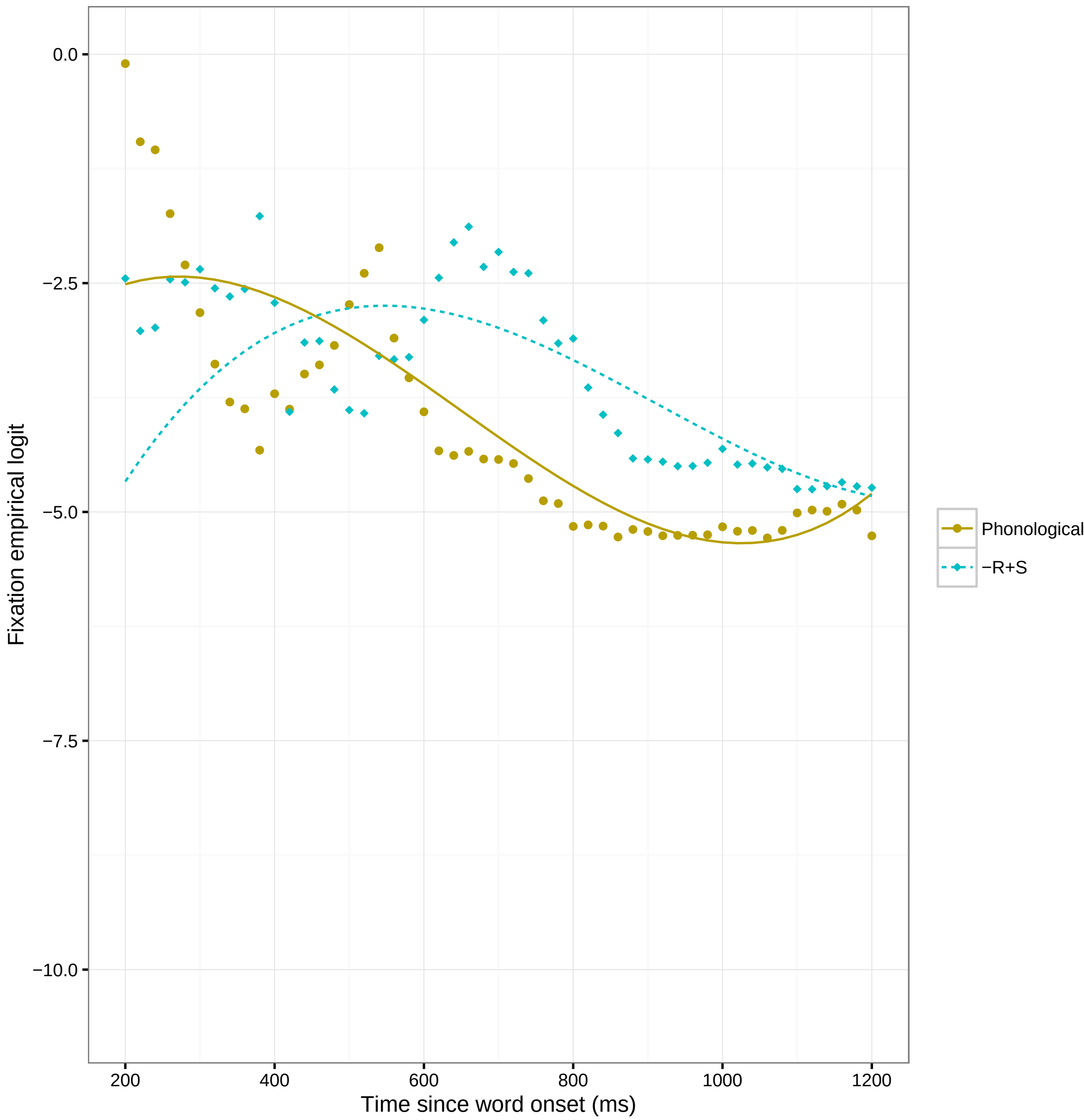

Figure B.9: Competitor fixation: observed data (symbols) and GCA model fits for Phonological versus -R+S

	Estimate	Std. Error	t-value	p-value
(Intercept)	1.018	0.504	2.021	0.043
Linear	19.053	1.913	9.959	0.000
Quadratic	-0.264	1.367	-0.193	0.847
Cubic	-4.694	1.201	-3.907	0.000
Condition	-0.956	0.640	-1.494	0.135
Linear:Condition	-4.133	0.900	-4.594	0.000
Quadratic:Condition	3.403	0.839	4.055	0.000
Cubic:Condition	3.098	0.813	3.811	0.000

Table B.10: Target fixation: empirical logit GCA results for Phonological (the reference condition) versus +R+S

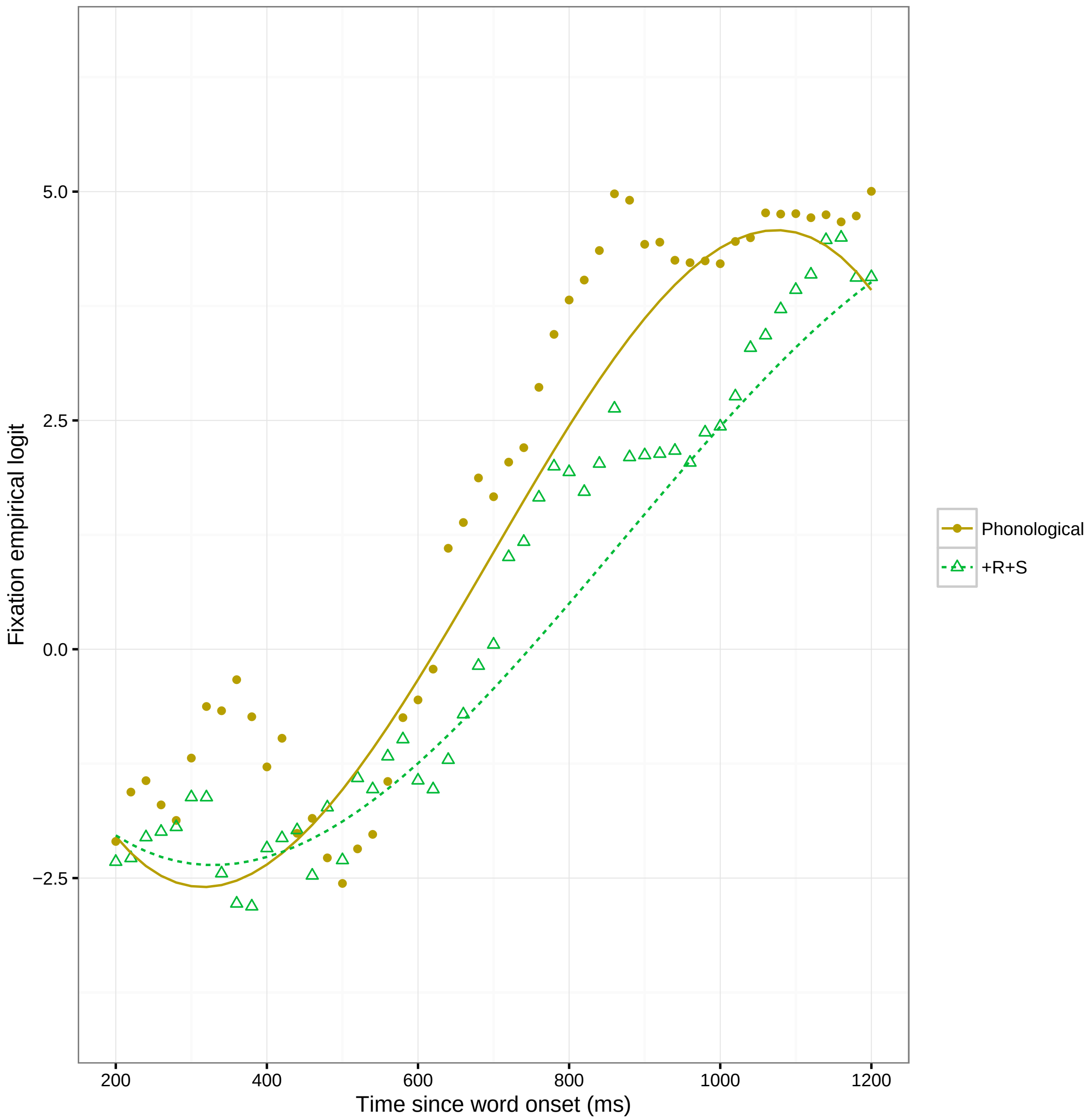

Figure B.10: Target fixation: observed data (symbols) and GCA model fits for Phonological versus +R+S

	Estimate	Std. Error	t-value	p-value
(Intercept)	-4.151	0.201	-20.612	0.000
Linear	-7.410	1.470	-5.041	0.000
Quadratic	3.781	1.648	2.294	0.022
Cubic	-0.733	1.428	-0.513	0.608
Condition	1.410	0.469	3.006	0.003
Linear:Condition	1.654	0.810	2.042	0.041
Quadratic:Condition	-5.669	0.770	-7.363	0.000
Cubic:Condition	0.205	0.750	0.273	0.785

Table B.11: Competitor fixation: Empirical logit GCA results for Phonological (the reference condition) versus +R+S

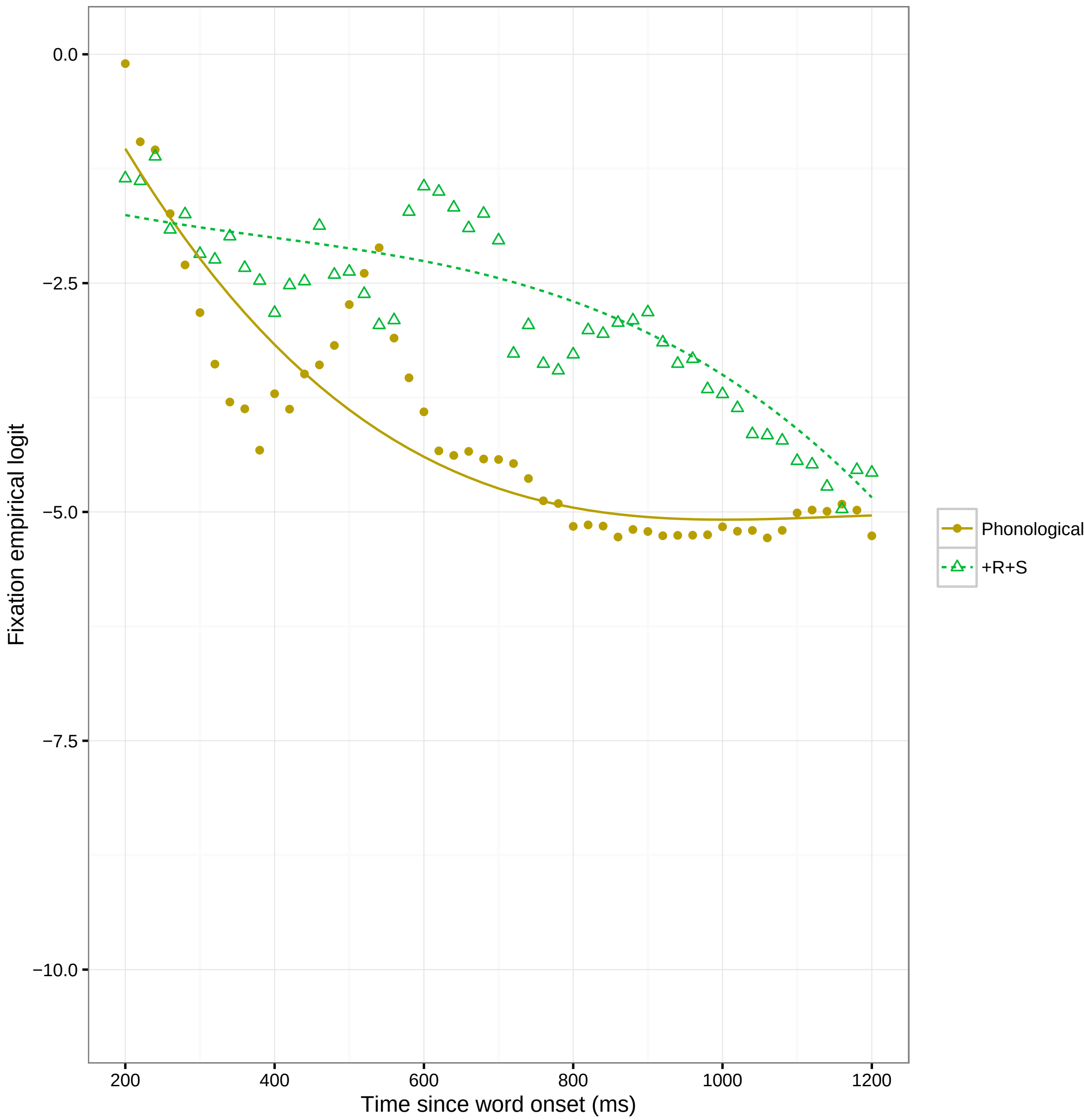

Figure B.11: Competitor fixation: observed data (symbols) and GCA model fits for Phonological versus +R+S

	Estimate	Std. Error	t-value	p-value
(Intercept)	0.020	0.610	0.033	0.974
Linear	13.969	2.262	6.175	0.000
Quadratic	4.131	1.839	2.246	0.025
Cubic	-1.903	1.712	-1.111	0.266
Condition	1.121	0.854	1.312	0.189
Linear:Condition	2.174	0.954	2.279	0.023
Quadratic:Condition	-2.637	0.855	-3.083	0.002
Cubic:Condition	-3.758	0.823	-4.569	0.000

Table B.12: Target fixation: empirical logit GCA results for +R+S (the reference condition) versus -R+S

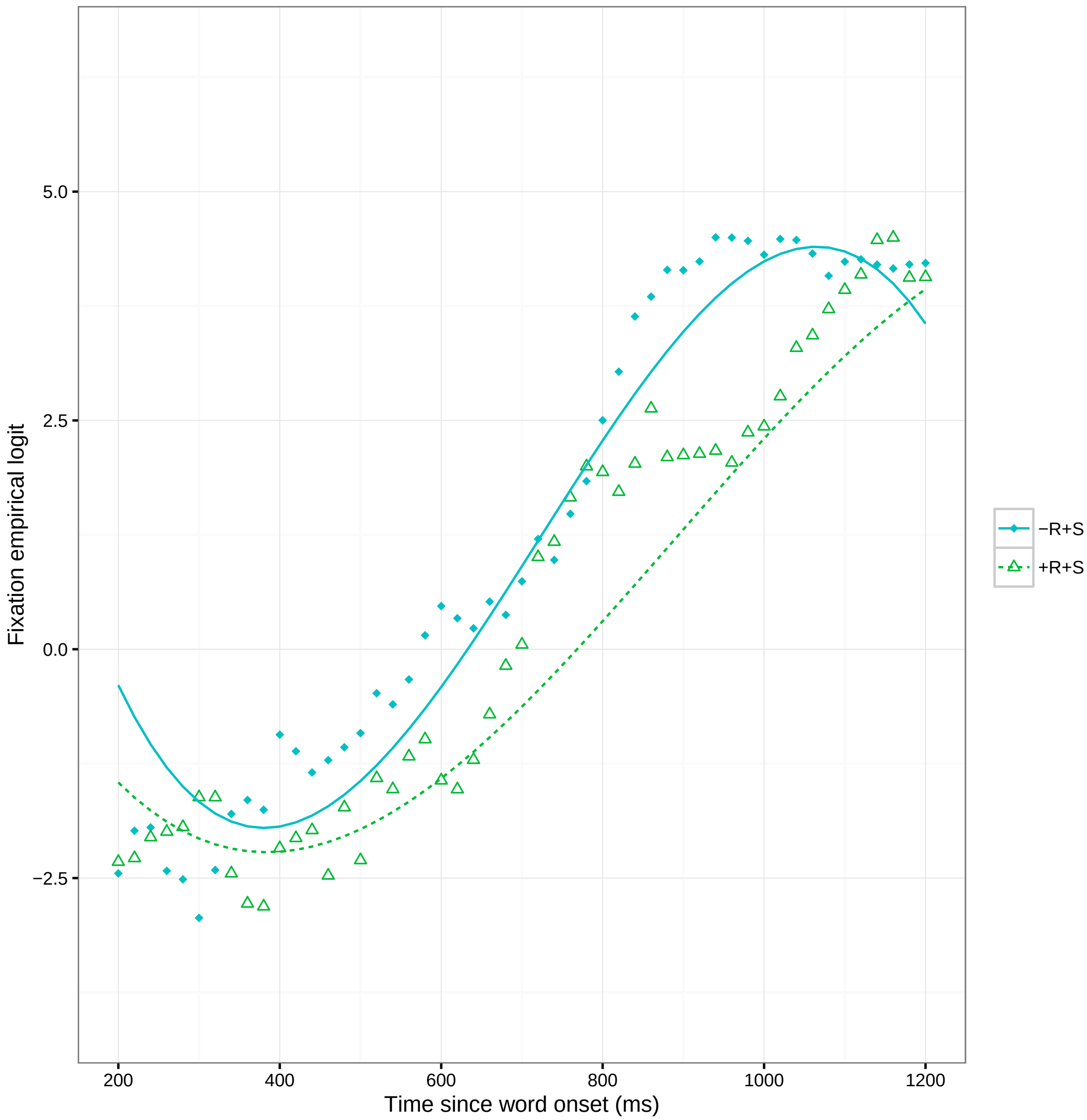

Figure B.12: Target fixation: observed data (symbols) and GCA model fits for +R+S versus -R+S

	Estimate	Std. Error	t-value	p-value
(Intercept)	-2.810	0.464	-6.049	0.000
Linear	-4.105	1.747	-2.350	0.019
Quadratic	-3.441	2.169	-1.586	0.113
Cubic	0.001	1.603	0.000	1.000
Condition	-0.574	0.656	-0.876	0.381
Linear:Condition	0.705	0.918	0.768	0.442
Quadratic:Condition	-0.321	0.835	-0.384	0.701
Cubic:Condition	2.220	0.799	2.780	0.005

Table B.13: Competitor fixation: Empirical logit GCA results for +R+S (the reference condition) versus -R+S

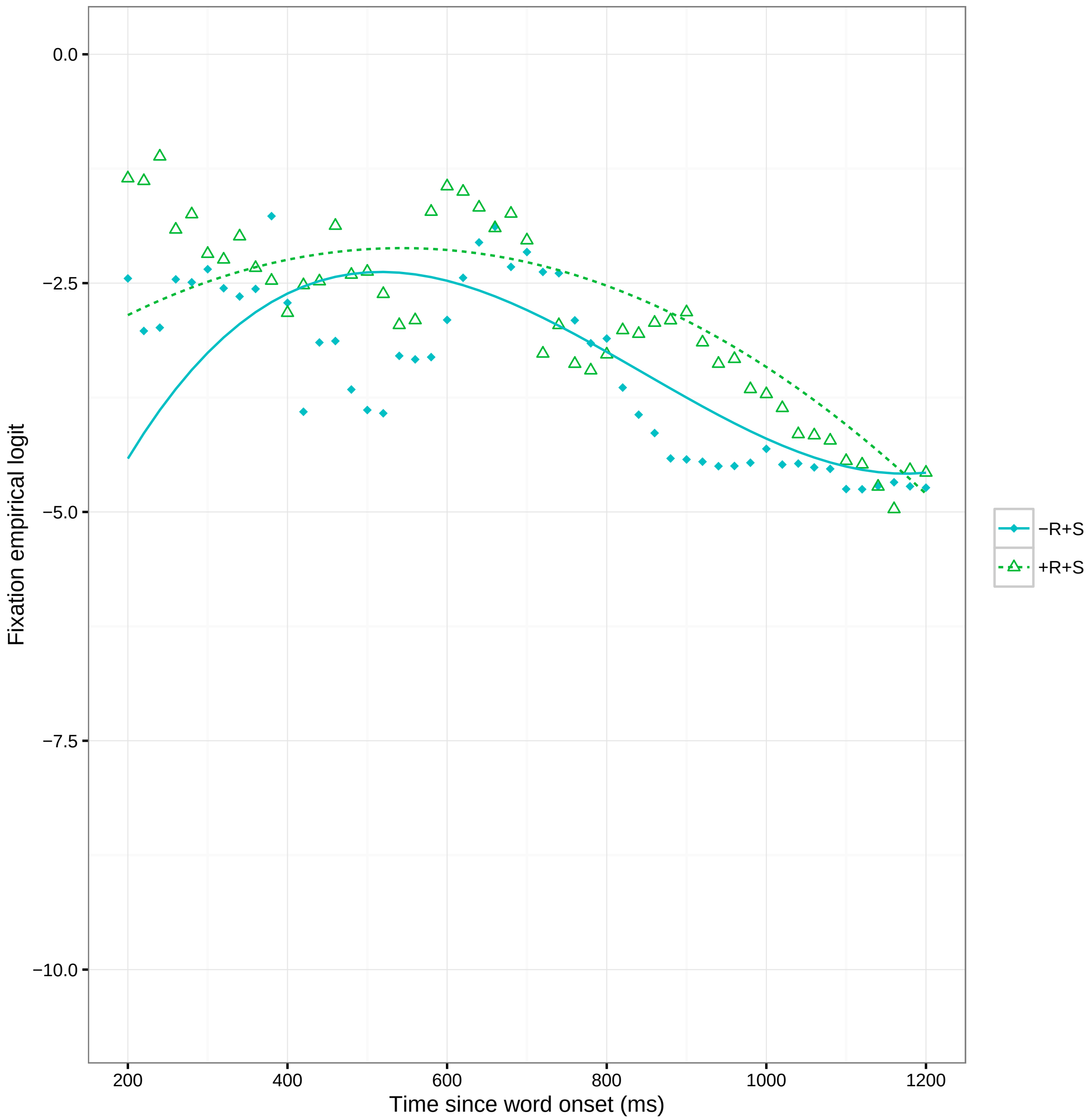

Figure B.13: Competitor fixation: observed data (symbols) and GCA model fits for -R+S versus +R+S

	Estimate	Std. Error	t-value	p-value
(Intercept)	0.851	0.468	1.817	0.069
Linear	18.363	1.661	11.053	0.000
Quadratic	0.139	2.034	0.068	0.946
Cubic	-3.116	1.477	-2.110	0.035
Condition	0.469	0.644	0.729	0.466
Linear:Condition	-3.422	1.045	-3.274	0.001
Quadratic:Condition	2.009	0.970	2.072	0.038
Cubic:Condition	-1.850	0.921	-2.007	0.045

Table B.14: Target fixation: empirical logit GCA results for +R-S (the reference condition) versus -R+S

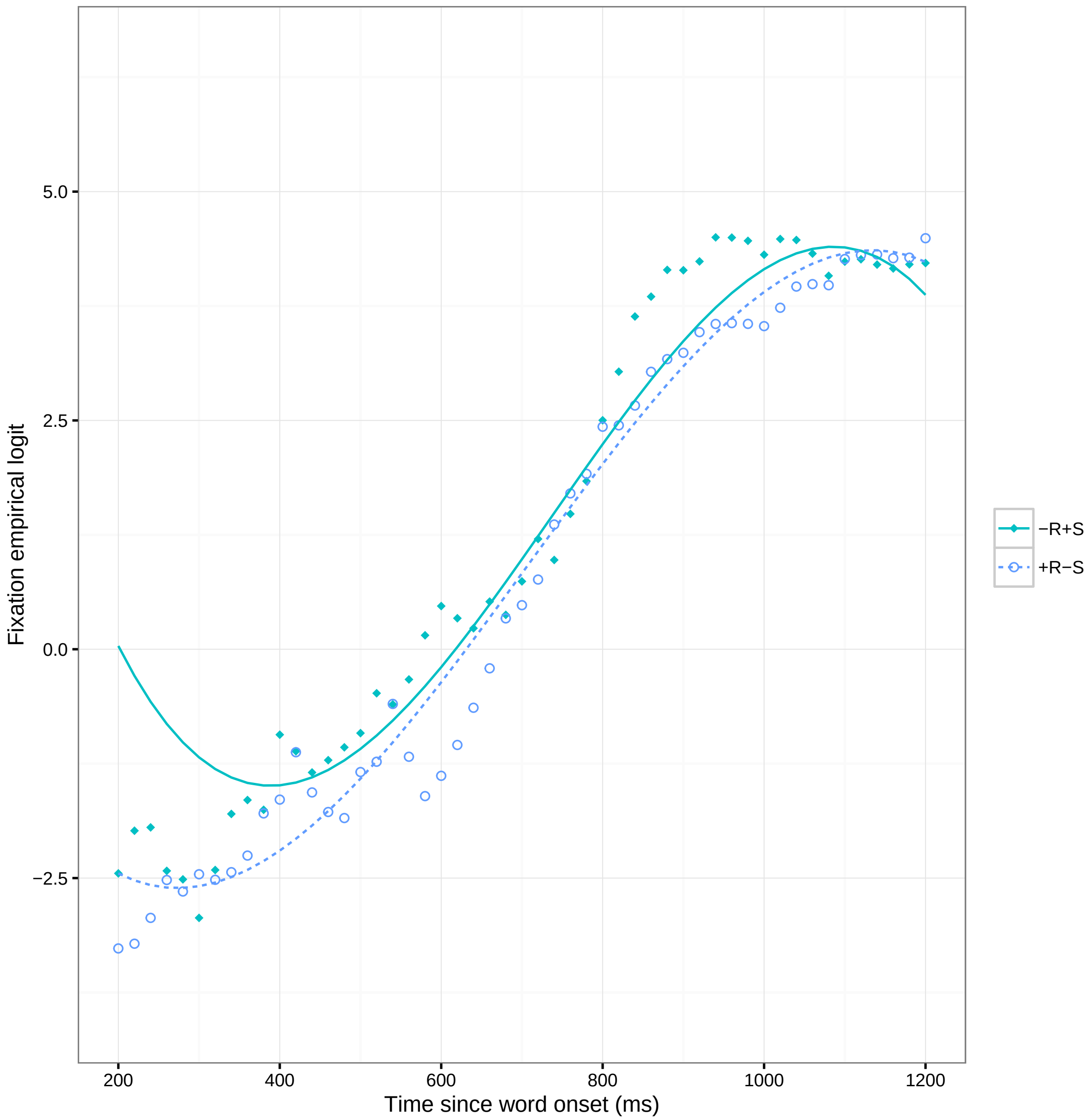

Figure B.14: Target fixation: observed data (symbols) and GCA model fits for +R-S versus -R+S

References

Abu-Rabia, S., & Awwad, J. S. (2004). Morphological structures in visual word recognition: The case of Arabic. *Journal of Research in Reading*, *27*(3), 321–336.

Alamri, A. A., & Zamuner, T. S. (2015). Phonological, semantic and root activation in spoken word recognition in Arabic: An eyetracking study. In *Proceedings of the annual conference of the canadian linguistics association* (pp. 1–15). Ottawa, Canada: Cahiers Linguistiques d'Ottawa.

Allopenna, P. D., Magnuson, J. S., & Tanenhaus, M. K. (1998). Tracking the time course of spoken word recognition using eye movements: Evidence for continuous mapping models. *Journal of Memory and Language*, *38*(4), 419–439.

Al-Nassir, A. A. (1993). *Sibawayh the phonologist: A critical study of the phonetic and phonological theory of Sibawayh as presented in his treatise Al-Kitab.* New York, NY: Kegan Paul International.

Andrews, S. (1992). Frequency and neighborhood effects on lexical access: Lexical similarity or orthographic redundancy? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *18*(2), 234.

Andrews, S., Miller, B., & Rayner, K. (2004). Eye movements and morphological segmentation of compound words: There is a mouse in mousetrap. *European Journal of Cognitive Psychology*, *16*(1–2), 285–311.

Apfelbaum, K. S., Blumstein, S. E., & McMurray, B. (2011). Semantic priming is affected by real-time phonological competition: Evidence for continuous cascading systems. *Psychonomic Bulletin and Review*, *18*(1), 141–149.

Arad, M. (2003). Locality constraints on the interpretation of roots: The case of Hebrew denominal verbs. *Natural Language and Linguistic Theory*, *21*(4), 737–778.

Baayen, H., Dijkstra, T., & Schreuder, R. (1997). Singulars and plurals in Dutch: Evidence for a parallel dual-route model. *Journal of Memory and Language*, *37*(1), 94–117.

Baayen, H., & Schreuder, R. (1999). War and peace: Morphemes and full forms in a noninteractive activation parallel dual-route model. *Brain and Language*, *68*(1), 27–32.

Bat-El, O. (1994). Stem modification and cluster transfer in Modern Hebrew. *Natural Language and Linguistic Theory*, *12*(4), 571–596.

Bat-El, O. (2003). Semitic verb structure within a universal perspective. *Language Acquisition and Language Disorders*, *28*, 29–60.

Bateson, M. (2003). *Arabic language handbook.* Washinton, DC: Georgetown University Press.

Bauer, L. (2002). What you can do with derivational morphology. In S. Bendjaballah,

W. U. Dressler, O. E. Pfeiffer, & M. D. Voeikova (Eds.), *Morphology 2000* (pp. 37–48). Amsterdam, The Netherlands: John Benjamins Publishing Co.

Benmamoun, E. (1999). Arabic morphology: The central role of the imperfective. *Lingua*, *108*(2), 175–201.

Benmamoun, E. (2003). The role of the imperfective template in Arabic morphology. *Language Acquisition and Language Disorders*, *28*, 99–114.

Bentrovato, S., Devescovi, A., D'amico, S., & Bates, E. (1999). Effect of grammatical gender and semantic context on lexical access in italian. *Journal of Psycholinguistic Research*, *28*(6), 677–693.

Berent, I., Vaknin, V., & Marcus, G. F. (2007). Roots, stems, and the universality of lexical representations: Evidence from Hebrew. *Cognition*, *104*(2), 254–286.

Bickel, B., & Nichols, J. (2007). Inflectional morphology. *Language Typology and Syntactic Description*, *3*(2), 169–240.

Bohas, G. (1997). *Matrices, étymons, racines: Eléments d'une théorie lexicologique du vocabulaire arabe [phonetic matrices, etymons, roots: Elements of an Arabic lexicological theory]*. Paris, France: Peeters.

Bohas, G. (2000). *Matrices et étymons: développements de la théorie [phonetic matrices and etymons: Development of the theory]*. Lausanne, France: Editions du Zèbre.

Bohas, G., & Guillaume, J.-P. (1984). *Etude des théories des grammairiens arabes: mophologie et phonologie [study of the theories of Arab grammarians: Morphology and phonology]* (Vol. 112). Damascus, Syria: Institut français de Damas.

Boudelaa, S. (2014). Is the Arabic mental lexicon morpheme-based or stem-based? implications for spoken and written word recognition. In *Handbook of Arabic literacy* (pp. 31–54). New York, NY: Springer.

Boudelaa, S., & Marslen-Wilson, W. D. (2000). Non-concatenative morphemes in language processing: Evidence from Modern Standard Arabic. In *Swap-2000* (pp. 23–26). Nijmegen, The Netherlands: ISCA.

Boudelaa, S., & Marslen-Wilson, W. D. (2001). Morphological units in the Arabic mental lexicon. *Cognition*, *81*(1), 65–92.

Boudelaa, S., & Marslen-Wilson, W. D. (2004). Abstract morphemes and lexical representation: The cv-skeleton in Arabic. *Cognition*, *92*(3), 271–303.

Boudelaa, S., & Marslen-Wilson, W. D. (2005). Discontinuous morphology in time: Incremental masked priming in Arabic. *Language and Cognitive Processes*, *20*(1-2), 207–260.

Boudelaa, S., & Marslen-Wilson, W. D. (2011). Productivity and priming: Morphemic decomposition in Arabic. *Language and Cognitive Processes*, *26*(4-6), 624–652.

Boudelaa, S., & Marslen-Wilson, W. D. (2015). Structure, form, and meaning in the mental lexicon: Evidence from Arabic. *Language, Cognition and Neuroscience*, *30*(8), 955–992.

Butterworth, B. (1983). Lexical representation. In B. Butterworth (Ed.), *Language production, (vol. 2)* (pp. 257–294). London, UK: Academic Press.

Cantineau, J. (1950). Racines et schèmes [Roots and patterns]. In W. Marçais (Ed.), *Mélanges [Mixtures]* (p. 119-124). Paris, France: Maisonneuve et Cie.

Caramazza, A., Laudanna, A., & Romani, C. (1988). Lexical access and inflectional morphology. *Cognition*, *28*(3), 297–332.

Cohen, A. (1986). Variance and variability of words in the speech chain. *Invariance and Variability in Speech Process*, 524–533.

Collins, A. M., & Loftus, E. F. (1975). A spreading-activation theory of semantic processing. *Psychological Review*, *82*(6), 407.

Cooper, R. M. (1974). The control of eye fixation by the meaning of spoken language: A new methodology for the real-time investigation of speech perception, memory, and language processing. *Cognitive Psychology*, *6*(1), 84–107.

Cubelli, R., Paolieri, D., Lotto, L., & Job, R. (2011). The effect of grammatical gender on object categorization. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *37*(2), 449.

Cutler, A., & Norris, D. (1988). The role of strong syllables in segmentation for lexical access. *Journal of Experimental Psychology: Human Perception and Performance*, *14*(1), 113.

Dahan, D. (2010). The time course of interpretation in speech comprehension. *Current Directions in Psychological Science*, *19*(2), 121–126.

Dahan, D., & Gaskell, M. G. (2007). The temporal dynamics of ambiguity resolution: Evidence from spoken-word recognition. *Journal of Memory and Language*, *57*(4), 483–501.

Dahan, D., & Magnuson, J. S. (2006). Spoken word recognition. *Handbook of Psycholinguistics*, *2*, 249–284.

Dahan, D., Magnuson, J. S., & Tanenhaus, M. K. (2001). Time course of frequency effects in spoken-word recognition: Evidence from eye movements. *Cognitive Psychology*, *42*(4), 317–367.

Deutsch, A., Frost, R., & Forster, K. I. (1998). Verbs and nouns are organized and accessed differently in the mental lexicon: evidence from hebrew. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *24*(5), 1238.

Diependaele, K., Sandra, D., & Grainger, J. (2005). Masked cross-modal morphological priming: Unravelling morpho-orthographic and morpho-semantic influences in early word recognition. *Language and Cognitive Processes*, *20*(1-2), 75–114.

Drews, E., & Zwitserlood, P. (1995). Morphological and orthographic similarity in visual word recognition. *Journal of Experimental Psychology: Human Perception and Performance*, *21*(5), 1098.

Duffy, S. A., & Keir, J. A. (2004). Violating stereotypes: Eye movements and comprehension processes when text conflicts with world knowledge. *Memory & Cognition*, *32*(4), 551–559.

Dufour, S. (2008). Phonological priming in auditory word recognition: When both controlled and automatic processes are responsible for the effects. *Canadian Journal of Experimental Psychology*, *62*(1), 33.

Dufour, S., & Peereman, R. (2003). Inhibitory priming effects in auditory word recognition: When the target's competitors conflict with the prime word. *Cognition*, *88*(3), B33–B44.

Dumay, N., Benraïss, A., Barriol, B., Colin, C., Radeau, M., & Besson, M. (2001). Behavioral and electrophysiological study of phonological priming between bisyllabic spoken words. *Journal of Cognitive Neuroscience*, *13*(1), 121–143.

Elman, J. L., & McClelland, J. L. (1983). *Speech perception as a* *cognitive process: The interactive activation model.* (Tech. Rep.). Defense Technical Information Center Document (ADA128787). Retrieved from http://www.dtic.mil/docs/citations/ADA128787.

Feldman, L. B., & Soltano, E. G. (1999). Morphological priming: The role of prime duration, semantic transparency, and affix position. *Brain and Language*, *68*(1), 33–39.

Fiorentino, R., & Poeppel, D. (2007). Compound words and structure in the lexicon. *Language and Cognitive processes*, *22*(7), 953–1000.

Forster, K. I. (1976). Accessing the mental lexicon. *New Approaches to Language Mechanisms*, *30*, 231–256.

Forster, K. I. (1979). Levels of processing and the structure of the language processor. In W. E. Cooper & E. C. T. Walker (Eds.), *Sentence processing: Psycholinguistic studies presented to Merrill Garrett* (Vol. 27, p. 85). Hillsdale, NJ: Lawrence Erlbaum Associates,.

Frauenfelder, U. H., & Tyler, L. K. (1987). The process of spoken word recognition: An introduction. *Cognition*, *25*(1-2), 1–20.

Frost, R., Deutsch, A., Gilboa, O., Tannenbaum, M., & Marslen-Wilson, W. (2000). Morphological priming: Dissociation of phonological, semantic, and morphological factors. *Memory and Cognition*, *28*(8), 1277–1288.

Frost, R., Forster, K. I., & Deutsch, A. (1997). What can we learn from the morphology of hebrew? a masked-priming investigation of morphological representation. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *23*(4), 829.

Gaskell, M. G., & Marslen-Wilson, W. D. (1997). Integrating form and meaning: A distributed model of speech perception. *Language and Cognitive Processes*, *12*(5-6), 613–656.

Gaskell, M. G., & Marslen-Wilson, W. D. (1999). Ambiguity, competition, and blending in spoken word recognition. *Cognitive Science*, *23*(4), 439–462.

Giraudo, H., & Grainger, J. (2000). Effects of prime word frequency and cumulative root frequency in masked morphological priming. *Language and Cognitive Processes*, *15*(4-5), 421–444.

Goldinger, S. D., Luce, P. A., & Pisoni, D. B. (1989). Priming lexical neighbors of spoken words: Effects of competition and inhibition. *Journal of Memory and Language*, *28*(5), 501–518.

Goldinger, S. D., Luce, P. A., Pisoni, D. B., & Marcario, J. K. (1992). Form-based priming in spoken word recognition: The roles of competition and bias. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *18*(6), 1211.

Goldsmith, J. (1976a). *Autosegmental phonolog* (Unpublished doctoral dissertation). MIT, Cambridge, Massachusetts.

Goldsmith, J. (1976b). An overview of autosegmental phonology. *Linguistic Analysis*, *2*, 23–68.

Gonnerman, L. M., Seidenberg, M. S., & Andersen, E. S. (2007). Graded semantic and phonological similarity effects in priming: Evidence for a distributed connectionist approach to morphology. *Journal of Experimental Psychology: General*, *136*(2), 323.

Grainger, J., Colé, P., & Segui, J. (1991). Masked morphological priming in visual word recognition. *Journal of Memory and Language*, *30*(3), 370–384.

Gwilliams, L., & Marantz, A. (2015). Non-linear processing of a linear speech stream: The influence of morphological structure on the recognition of spoken Arabic words. *Brain and Language*, *147*, 1–13.

Hamburger, M., & Slowiaczek, L. M. (1996). Phonological priming reflects lexical competition. *Psychonomic Bulletin and Review*, *3*(4), 520–525.

Heath, J. (2003). Arabic derivational ablaut, processing strategies, and consonantal "roots". In J. Shimron (Ed.), *Language processing and acquisition in languages of Semitic root-based morphology* (p. 100-115). Amsterdam, The Netherlands: John Benjamins.

Henderson, L., Wallis, J., & Knight, D. (1984). Morphemic structure and lexical access. *Attention and Performance*, *10*, 211–226.

Holes, C. (2004). *Modern Arabic: Structures, functions, and varieties.* Washington, DC: Georgetown University Press.

Huettig, F., & Altmann, G. T. (2005). Word meaning and the control of eye fixation: Semantic competitor effects and the visual world paradigm. *Cognition*, *96*(1), B23–B32.

Huettig, F., Quinlan, P. T., McDonald, S. A., & Altmann, G. T. (2006). Models of high-dimensional semantic space predict language-mediated eye movements in the visual world. *Acta psychologica*, *121*(1), 65–80.

Huettig, F., Rommers, J., & Meyer, A. S. (2011). Using the visual world paradigm to study language processing: A review and critical evaluation. *Acta psychologica*, *137*(2), 151–171.

Hutchison, K. A. (2003). Is semantic priming due to association strength or feature overlap? A microanalytic review. *Psychonomic Bulletin and Review*, *10*(4), 785–813.

Jared, D., Jouravlev, O., & Joanisse, M. (2016). The effect of semantic transparency on the processing of morphologically derived words: Evidence from decision latencies and event-related potentials. *Journal of experimental psychology. Learning, memory, and cognition*, 1-29.

Jusczyk, P. W., & Luce, P. A. (2002). Speech perception and spoken word recognition: Past and present. *Ear and Hearing*, *23*(1), 2–40.

Kielar, A., & Joanisse, M. F. (2010). Graded effects of regularity in language revealed by n400 indices of morphological priming. *Journal of Cognitive Neuroscience*, *22*(7), 1373–1398.

Kielar, A., & Joanisse, M. F. (2011). The role of semantic and phonological factors in word recognition: An ERP cross-modal priming study of derivational morphology. *Neuropsychologia*, *49*(2), 161–177.

Longtin, C.-M., Segui, J., & Halle, P. A. (2003). Morphological priming without morphological relationship. *Language and Cognitive Processes*, *18*(3), 313–334.

Luce, P. A., & Pisoni, D. B. (1998). Recognizing spoken words: The neighborhood activation model. *Ear and Hearing*, *19*(1), 1.

MacCarthy, J., & Prince, A. (1993). *Prosodic morphology: Constraint interaction and satisfaction.* Rutgers Center for Cognitive Science.

Magnuson, J. S., Dahan, D., Allopenna, P. D., Tanenhaus, M. K., & Aslin, R. N. (1998). Using an artificial lexicon and eye movements to examine the development and microstructure of lexical dynamics. In M. A. Gernsbacher & S. J. Derry (Eds.), *Proc.*

of the twentieth annual conference of the cognitive science society (pp. 651–656). London, UK: Lawrence Erlbaum Associates.

Magnuson, J. S., Tanenhaus, M. K., Aslin, R. N., & Dahan, D. (1999). Spoken word recognition in the visual world paradigm reflects the structure of the entire lexicon. In M. Hahn & S. C. Stoness (Eds.), *Proceedings of the twenty first annual conference of the cognitive science society* (pp. 331–336). London, UK: Lawrence Erlbaum Associates.

Mahfoudhi, A. (2005). *Morphological and phonological units in the Arabic mental lexicon: Implications for theories of morphology and lexical processing* (Unpublished doctoral dissertation). University of Ottawa, Ottawa, Canada.

Manelis, L., & Tharp, D. A. (1977). The processing of affixed words. *Memory and Cognition*, *5*(6), 690–695.

Marslen-Wilson, W. (1987). Functional parallelism in spoken word-recognition. *Cognition*, *25*(1), 71–102.

Marslen-Wilson, W., Moss, H. E., & van Halen, S. (1996). Perceptual distance and competition in lexical access. *Journal of Experimental Psychology: Human Perception and Performance*, *22*(6), 1376.

Marslen-Wilson, W., & Tyler, L. K. (1980). The temporal structure of spoken language understanding. *Cognition*, *8*(1), 1–71.

Marslen-Wilson, W., Tyler, L. K., Waksler, R., & Older, L. (1994). Morphology and meaning in the English mental lexicon. *Psychological Review*, *101*(1), 3.

Marslen-Wilson, W., & Welsh, A. (1978). Processing interactions and lexical access during word recognition in continuous speech. *Cognitive Psychology*, *10*(1), 29–63.

Marslen-Wilson, W., & Zwitserlood, P. (1989). Accessing spoken words: The importance of word onsets. *Journal of Experimental Psychology: Human Perception and Performance*, *15*(3), 576.

Matin, E., Shao, K., & Boff, K. R. (1993). Saccadic overhead: Information-processing time with and without saccades. *Perception and Psychophysics*, *53*(4), 372–380.

McCarthy, J. (1979). *Formal problems in semitic morphology and phonology.* (Doctoral dissertation). MIT, Cambridge, MA.

McCarthy, J. (1981). A prosodic theory of nonconcatenative morphology. *Linguistic Inquiry*, *12*(3), 373–418.

McCarthy, J. (1986). OCP effects: Gemination and antigemination. *Linguistic Inquiry*, *17*(2), 207–263.

McCarthy, J. (2006). Prosodic morphology. In K. Brown (Ed.), *Encyclopedia of language and linguistics: Second edition.* Amsterdam, The Netherlands: Elsevier.

McCarthy, J., & Prince, A. (1990a). Foot and word in prosodic morphology: The Arabic broken plural. *Natural Language and Linguistic Theory*, *8*(2), 209–283.

McCarthy, J., & Prince, A. (1990b). Prosodic morphology and templatic morphology. In M. Eid & J. McCarthy (Eds.), *Perspectives on Arabic linguistics ii: papers from the second annual symposium on Arabic linguistics* (pp. 1–54). Amsterdam, The Netherlands: John Benjamins Publishing.

McClelland, J. (1987). The case for interactionism in language processing. In M. Coltheart (Ed.), *Attention and performance XII: The Psychology of Reading* (pp. 1–36). London, UK: Erlbaum.

McClelland, J., & Elman, J. (1986). The TRACE model of speech perception. *Cognitive Psychology*, *18*(1), 1–86.
McClelland, J., & Rumelhart, D. (1981). An interactive activation model of context effects in letter perception: I. An account of basic findings. *Psychological Review*, *88*(5), 375.
McMurray, B., Tanenhaus, M. K., Aslin, R. N., & Spivey, M. J. (2003). Probabilistic constraint satisfaction at the lexical/phonetic interface: Evidence for gradient effects of within-category VOT on lexical access. *Journal of Psycholinguistic Research*, *32*(1), 77–97.
McNamara, T. P. (2005). *Semantic priming: Perspectives from memory and word recognition.* Hove, UK: Psychology Press.
McQueen, J. M., & Cutler, A. (1998). Morphology in word recognition. In A. M. Zwicky & S. A (Eds.), *The handbook of morphology* (pp. 406–427). Oxford, UK: Blackwell.
Meyer, A. S., & Schriefers, H. (1991). Phonological facilitation in picture-word interference experiments: Effects of stimulus onset asynchrony and types of interfering stimuli. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *17*(6), 1146.
Mimouni, Z., Kehayia, E., & Jarema, G. (1998). The mental representation of singular and plural nouns in Algerian Arabic as revealed through auditory priming in agrammatic aphasic patients. *Brain and Language*, *61*(1), 63–87.
Mirman, D. (2014). *Growth curve analysis and visualization using R.* Boca Raton, FL: CRC Press.
Mirman, D., Dixon, J. A., & Magnuson, J. S. (2008). Statistical and computational models of the visual world paradigm: Growth curves and individual differences. *Journal of Memory and Language*, *59*(4), 475–494.
Mirman, D., & Magnuson, J. S. (2009). Dynamics of activation of semantically similar concepts during spoken word recognition. *Memory and Cognition*, *37*(7), 1026–1039.
Monsell, S., & Hirsh, K. W. (1998). Competitor priming in spoken word recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *24*(6), 1495.
Morton, J. (1969). Interaction of information in word recognition. *Psychological Review*, *76*(2), 165.
Moss, H. E., McCormick, S., & Tyler, L. K. (1997). The time course of activation of semantic information during spoken word recognition. *Language and Cognitive Processes*, *12*(5-6), 695–732.
Norris, D. (1994). Shortlist: A connectionist model of continuous speech recognition. *Cognition*, *52*(3), 189–234.
Norris, D., & McQueen, J. M. (2008). Shortlist B: A Bayesian model of continuous speech recognition. *Psychological Review*, *115*(2), 357.
Paterson, K. B., Alcock, A., & Liversedge, S. P. (2011). Morphological priming during reading: Evidence from eye movements. *Language and Cognitive Processes*, *26*(4-6), 600–623.
Pisoni, D. B., & Luce, P. A. (1987). Acoustic-phonetic representations in word recognition. *Cognition*, *25*(1-2), 21–52.
Plaut, D. C., & Gonnerman, L. M. (2000). Are non-semantic morphological effects incompatible with a distributed connectionist approach to lexical processing? *Language*

and Cognitive Processes, *15*(4-5), 445–485.

Pollatsek, A., Hyönä, J., & Bertram, R. (2000). The role of morphological constituents in reading Finnish compound words. *Journal of Experimental Psychology: Human Perception and Performance*, *26*(2), 820.

Qasem, M. (2010). *Morphological decomposition in Arabic: Dissociation of form and semantic effects.* (Unpublished doctoral dissertation). Michigan State University, East Lansing, MI.

Radeau, M., Morais, J., & Dewier, A. (1989). Phonological priming in spoken word recognition: Task effects. *Memory and Cognition*, *17*(5), 525–535.

Radeau, M., Morais, J., & Segui, J. (1995). Phonological priming between monosyllabic spoken words. *Journal of Experimental Psychology: Human Perception and Performance*, *21*(6), 1297.

Rastle, K., & Davis, M. H. (2008). Morphological decomposition based on the analysis of orthography. *Language and Cognitive Processes*, *23*(7-8), 942–971.

Rastle, K., Davis, M. H., Marslen-Wilson, W. D., & Tyler, L. K. (2000). Morphological and semantic effects in visual word recognition: A time-course study. *Language and Cognitive Processes*, *15*(4-5), 507–537.

Rastle, K., Davis, M. H., & New, B. (2004). The broth in my brother's brothel: Morpho-orthographic segmentation in visual word recognition. *Psychonomic Bulletin and Review*, *11*(6), 1090–1098.

Ratcliffe, R. R. (1997). Prosodic templates in a word-based morphological analysis of Arabic. *Amsterdam Studies in the Theory and History of Linguistic Science*, *4*, 147–172.

Rueckl, J. G., Mikolinski, M., Raveh, M., Miner, C. S., & Mars, F. (1997). Morphological priming, fragment completion, and connectionist networks. *Journal of Memory and Language*, *36*(3), 382–405.

Ryding, K. C. (2005). *A reference grammar of Modern Standard Arabic.* Cambridge, UK: Cambridge University Press.

Salverda, A. P., Kleinschmidt, D., & Tanenhaus, M. K. (2014). Immediate effects of anticipatory coarticulation in spoken-word recognition. *Journal of Memory and Language*, *71*(1), 145–163.

Schluter, K. T. (2013). *Hearing words without structure: Subliminal speech priming and the organization of the moroccan arabic lexicon* (Unpublished doctoral dissertation). The University of Arizona, Tucson, AR.

Schreuder, R., & Baayen, H. (1995). *Modeling morphological processing* (Morphological aspects of language processing ed.; L. B. Feldman, Ed.). Hillsdale, NJ: Lawrence Erlbaum Associates Inc.

Schreuder, R., & Baayen, R. H. (1997). How complex simplex words can be. *Journal of Memory and Language*, *37*(1), 118–139.

Seidenberg, M. S., & Gonnerman, L. M. (2000). Explaining derivational morphology as the convergence of codes. *Trends in Cognitive Sciences*, *4*(9), 353–361.

Shoemaker, E. M. (2009). *Acoustic cues to speech segmentation in spoken French: Native and non-native strategies* (Unpublished doctoral dissertation). The University of Texas at Austin, Austin, TX.

Slowiaczek, L. M., & Hamburger, M. (1992). Prelexical facilitation and lexical interference in auditory word recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *18*(6), 1239.

Slowiaczek, L. M., McQueen, J. M., Soltano, E. G., & Lynch, M. (2000). Phonological representations in prelexical speech processing: Evidence from form-based priming. *Journal of Memory and Language*, *43*(3), 530–560.

Slowiaczek, L. M., Nusbaum, H. C., & Pisono, D. B. (1987). Phonological priming in auditory word recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *13*(1), 64.

Slowiaczek, L. M., & Pisoni, D. B. (1986). Effects of phonological similarity on priming in auditory lexical decision. *Memory and Cognition*, *14*(3), 230–237.

Smolka, E., Komlosi, S., & Rösler, F. (2009). When semantics means less than morphology: The processing of German prefixed verbs. *Language and Cognitive Processes*, *24*(3), 337–375.

Steriade, D. (1988). Reduplication and syllable transfer in sanskrit and elsewhere. *Phonology*, *5*(01), 73–155.

Taft, M. (1981). Prefix stripping revisited. *Journal of Verbal Learning and Verbal Behavior*, *20*(3), 289–297.

Taft, M. (1986). Lexical access codes in visual and auditory word recognition. *Language and Cognitive Processes*, *1*(4), 297–308.

Taft, M. (1988). A morphological-decomposition model of lexical representation. *Linguistics*, *26*(4), 657–668.

Taft, M. (1994). Interactive-activation as a framework for understanding morphological processing. *Language and Cognitive Processes*, *9*(3), 271–294.

Taft, M., & Ardasinski, S. (2006). Obligatory decomposition in reading prefixed words. *The Mental Lexicon*, *1*(2), 183–199.

Taft, M., & Forster, K. I. (1975). Lexical storage and retrieval of prefixed words. *Journal of Verbal Learning and Verbal Behavior*, *14*(6), 638–647.

Taft, M., & Kougious, P. (2004). The processing of morpheme-like units in monomorphemic words. *Brain and Language*, *90*(1), 9–16.

Taft, M., & Nguyen-Hoan, M. (2010). A sticky stick? The locus of morphological representation in the lexicon. *Language and Cognitive Processes*, *25*(2), 277–296.

Tanenhaus, M. K., Spivey-Knowlton, M. J., Eberhard, K. M., & Sedivy, J. C. (1995). Integration of visual and linguistic information in spoken language comprehension. *Science*, *268*(5217), 1632–1634.

Twist, A. E. (2006). *A psycholinguistic investigation of the verbal morphology of Maltese* (Unpublished doctoral dissertation). The University of Arizona, Tucson, AR.

Tyler, L. K., Marslen-Wilson, W., Rentoul, J., & Hanney, P. (1988). Continuous and discontinuous access in spoken word-recognition: The role of derivational prefixes. *Journal of Memory and Language*, *27*(4), 368–381.

Ussishkin, A. (1999). The inadequacy of the consonantal root: Modern Hebrew denominal verbs and output–output correspondence. *Phonology*, *16*(03), 401–442.

Ussishkin, A. (2005). A fixed prosodic theory of nonconcatenative templaticmorphology. *Natural Language & Linguistic Theory*, *23*(1), 169–218.

Ussishkin, A. (2006). Semitic morphology: Root-based or word-based? *Morphology*, *16*(1), 37–40.

Ussishkin, A., Dawson, C. R., Wedel, A., & Schluter, K. (2015). Auditory masked priming in Maltese spoken word recognition. *Language, Cognition and Neuroscience*, *30*(9), 1096–1115.

Vaissiere, J. (1986). Variance and invariance at the word level. In J. S. Perkel & D. H. Klatt (Eds.), *Invariance and variability in speech process* (pp. 534–539). Mahwah, NJ: Lawrence Erlbaum Associates.

Watson, J. C. (2007). *The phonology and morphology of Arabic.* Oxford, UK: Oxford University Press.

Weber, A., & Scharenborg, O. (2012). Models of spoken-word recognition. *Wiley Interdisciplinary Reviews: Cognitive Science*, *3*(3), 387–401.

Wray, S. (2016). *Decomposability and the effects of morpheme frequency in lexical access* (Unpublished doctoral dissertation). The University of Arizona, Tucson, AR.

Wright, W. (1967). *A grammar of Arabic language. (vol. 1, 3rd ed.).* Cambridge, England: Cambridge University Press.

Yee, E., & Sedivy, J. C. (2006). Eye movements to pictures reveal transient semantic activation during spoken word recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *32*(1), 1.

Zamuner, T. S., Moore, C., & Desmeules-Trudel, F. (2016). Toddlers sensitivity to within-word coarticulation during spoken word recognition: Developmental differences in lexical competition. *Journal of Experimental Child Psychology*, *152*, 136–148.

Zwitserlood, P. (1989). The locus of the effects of sentential-semantic context in spoken-word processing. *Cognition*, *32*(1), 25–64.

Zwitserlood, P., Bolwiender, A., & Drews, E. (2005). Priming morphologically complex verbs by sentence contexts: Effects of semantic transparency and ambiguity. *Language andCognitive Processes*, *20*(1-2), 395–415.