

The Role of Morphology in Word Recognition of Hebrew as a Templatic Language

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Abstract

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Research on recognition of complex words has primarily focused on affixational complexity in concatenative languages. This dissertation investigates both templatic and affixational complexity in Hebrew, a templatic language, with particular focus on the role of the root and template morphemes in recognition. It also explores the role of morphology in word recognition across modality (visual vs. auditory). Finally, it investigates whether acquisition of visual word recognition processes in Hebrew by speakers of a concatenative (non-templatic) language is dependent upon age of acquisition or age of arrival.

The findings for native speakers in this dissertation suggest that both templatic words and affixed words in Hebrew are decomposed into their constituent morphemes and for templatic words this decomposition is the default. In templatic words, the root and template play different roles in recognition. For nouns the role of the root is particularly important, as evidenced by sensitivity to letter position, while for verbs both roots and templates play key roles (Chapter 4). A phonemic restoration paradigm provides evidence of templatic morphology playing a key role in auditory word recognition. As with visual recognition of nouns, roots play an important role in auditory noun recognition as evidenced by words with root sounds masked being harder to recover than words with template sounds masked

(Chapter 5). In Hebrew, as with concatenative languages, inflectional words show evidence of decomposition into stem and affix with a larger amplitude N400 for inflectionally affixed templatic words than unaffixed ones. Furthermore, higher processing costs are revealed for concatenative borrowings into the language than templatic words, with greater amplitude peakers in the 200-300 ms time-window, suggesting that for templatic words decomposition is the default strategy (Chapter 6).

Results of the L2 Hebrew study suggest that even proficient readers show transfer effects from a concatenative L1. Unlike native readers, they are letter position flexible for root letters in nouns with nouns with transposed letters priming, suggesting that a whole-stem representation of templatic words is available. These effects are not shown to correlate with either age of acquisition or arrival (Chapter 7).

TABLE OF CONTENTS

	Page
List of Figures	vi
List of Tables	vii
Chapter 1: Introduction	1
1.1 Chapter goals	1
1.2 Dissertation Goals and Research Questions	1
1.3 Dissertation Outline	4
Chapter 2: Intro to Semitic Morphology: Examples from Hebrew and Arabic	6
2.1 Chapter goals	6
2.2 Semitic Language Branch	6
2.2.1 Semitic Language Trees	6
2.2.2 Background of Modern Hebrew and Modern Standard Arabic as Semitic Languages	8
2.2.3 Modern Standard Arabic	8
2.2.4 Birth of Modern Hebrew	10
2.3 Morphological Structure: What makes up a Semitic word	11
2.3.1 The Root and the Morpheme	11
2.3.2 Templatic Morphology	13
2.3.3 Inflectional Morphology	16
2.3.4 Morphology and the Writing System: Reading without Vowels	18
2.4 Semitic Morphology: Theoretical Frameworks	19
2.4.1 Autosegmental Approach: The Three Morpheme Tier	19
2.4.2 Generalized Templatic Theory GTT	20
2.4.3 Etymons	22
2.4.4 Current Approach	24

Chapter 3: Literature Review: Models of Word Recognition and Lexical Access . . .	25
3.1 Chapter goals	25
3.2 Role of Morphology in Visual Word Recognition	25
3.2.1 Evidence for Decomposition into Stems and Affixes	26
3.2.2 Morphology in Concatenative Languages: Types of Affixation	27
3.2.3 Morphology in Templatic Languages	29
3.3 Models of Visual Word Recognition and Orthographic Encoding	30
3.3.1 Model Considerations	30
3.3.2 Lexicalist Reading Models	33
3.3.3 Models of Reading Complex Words	38
3.4 Time Course of Visual Word Recognition	42
3.4.1 Word Recognition and Early Effects	43
3.4.2 Semantic Integration	43
3.4.3 Syntactic Integration	44
3.4.4 A Timeline	44
3.5 Auditory Word Recognition:General Considerations	45
3.5.1 Uniqueness Point	46
3.6 Role of Morphology in Auditory Word Recognition	49
3.6.1 Concatenative Languages: Recognizing Complex Words	49
3.6.2 Templatic Languages	50
3.7 Models of Auditory Word Recognition	50
3.7.1 Models	50
3.8 Time Course of Auditory Word Recognition	54
3.9 Conclusion	55
Chapter 4: New Findings in Transposed Letter Effects in A Templatic Language: Verbs versus Nouns and Roots vs Templates	56
4.1 Chapter goals	56
4.2 Background	56
4.3 Study 1: Transpositions in Root versus Template Morphemes	59
4.3.1 Methodological Considerations	59
4.3.2 Experiment 1: Root Transpositions in Nouns <i>Replication and Extension of Previous Findings</i>	60

4.3.3	Experiment 2: Templates Transpositions in Verbs	65
4.3.4	Experiment 3: Root and Template Transpositions in Nouns	70
4.4	Study 2: Transpositions in Roots and Templates in Nouns vs. Verbs	74
4.4.1	Methodological Considerations	74
4.4.2	Experiment 1: Root Transpositions in Nouns vs. Verbs	75
4.4.3	Experiment 2: Root and Template Transpositions in Nouns vs. Verbs	81
4.4.4	Experiment 3: Template Transpositions in Verbs	84
4.5	Overall Discussion and Future Directions	87
4.5.1	Reading Verbs vs Nouns	87
4.5.2	Further Questions	89
Chapter 5:	Auditory Word Recognition in a Templatic Language: The role of the Root	90
5.1	Chapter goals	90
5.2	Introduction	90
5.2.1	Visual vs. Auditory Lexical Access	90
5.2.2	Benefits of an Auditory Approach: Escape from Orthography	91
5.2.3	Phonemic Restoration	92
5.2.4	Co-Articulation and Other Methodological Considerations	93
5.3	Experiment 1: Masking in Templatic vs Concatenative Words in a Templatic Language	94
5.3.1	Methods	94
5.3.2	Results	97
5.3.3	Discussion and Conclusions	98
5.4	Experiment 2: Masking in Root vs Template (Preliminary results)	99
5.4.1	Methods	99
5.4.2	Results	101
5.4.3	Discussion and Conclusions	101
5.5	General Discussion and Future Directions	102
Chapter 6:	Reading Words with Templatic and Inflectional Complexity: An ERP Study	104
6.1	Chapter goals	104
6.2	Introduction and Background	104

6.2.1	Time-Line of Recognition of Complex Words	105
6.2.2	Previous ERP and MEG Work	105
6.2.3	Summary of Observations	109
6.2.4	Current Study: Research Questions and Predictions	110
6.3	Methods	112
6.3.1	Participants	112
6.3.2	Materials	114
6.3.3	Procedure	115
6.3.4	Data Acquisition and Analysis	115
6.4	Results	117
6.4.1	Behavioral Results	117
6.4.2	Conatenative: Affixed vs Unaffixed	119
6.4.3	Templatic: Affixed vs Unaffixed	120
6.4.4	Templatic vs Concatenative	121
6.4.5	Summary	122
6.5	Discussion and Further Research	123
6.5.1	Behavioral and ERP Findings	123
6.5.2	Implications for Reading Models	125
6.5.3	Further Research	126
Chapter 7:	Reading a Templatic Language as a Second Language	128
7.1	Chapter goals	128
7.2	Introduction and Background	128
7.2.1	Age of Acquisition and Reading Proficiency	129
7.2.2	Transfer Effects	131
7.2.3	Masked Priming in a Second Language	132
7.2.4	General Research Questions	132
7.3	Experiment 1: Root Transposition in Nouns	133
7.3.1	Methods	134
7.3.2	Stimuli	135
7.3.3	Results	138
7.3.4	Discussion	138
7.4	Experiment 2: Root Transpositions in Verbs	139

7.4.1	Methods	139
7.4.2	Results	140
7.4.3	Discussion	140
7.5	Age of Acquisition and Arrival as Predictors of Individual Differences-An Individual Differences Analysis of Experiments 1 and 2	140
7.5.1	Predictions	141
7.5.2	Methods	143
7.5.3	Results	144
7.5.4	Root Transpositions in Verbs	144
7.5.5	Discussion	145
7.5.6	General Discussion and Further Directions	148
Chapter 8:	Conclusions and Further Directions	150
8.1	Chapter goals	150
8.2	General Discussion and Conclusions	150
8.2.1	Role of the Root and Template in Templatic word Recognition and Interaction with Lexical Category	151
8.2.2	Role of Morphology Across Modalities: Visual vs. Auditory	151
8.2.3	Decomposition as a Default Mechanism for Hebrew Stems	152
8.2.4	Inflectional Affixation in a Templatic Language	152
8.2.5	Theoretical Implications	153
8.2.6	Reading Hebrew as a Second Language: Transfer from Concatenative Languages	155
8.3	Future Directions	155

LIST OF FIGURES

Figure Number	Page
2.1 Adapted from Hetzron (1976) Classification of Semitic languages	7
2.2 Three Tier Structure: word <i>gidel</i> , adapted from McCarthy (1985, 1979)	21
2.3 Adapted from Ussishkin (2005), illustrates prosodic word in GTT with the word <i>katab</i>	23
4.1 Box and Whisker Plot reflecting skewed distribution of RTs	86
5.1 Masking: Before and After	96
6.1 Concatenative: Affixed vs Un-affixed	119
6.2 Templatic: Affixed vs Un-affixed. (Time-window with significant effect is shaded on the CZ electrode)	120
6.3 Concatenative vs Templatic (Time-windows with significant effect are shaded on the CZ electrode)	122
7.1 Transposed Letter Priming effects normalized by subject (ID-TL/Average RT) by Age of Acquisition in root transpositions of nouns	145
7.2 Transposed Letter Priming effects normalized by subject (ID-TL/Average RT) by Age of Arrival in root transpositions of nouns	146
7.3 Transposed Letter Priming effects normalized by subject (ID-TL/Average RT) by Age of Acquisition in root transpositions of verbs	147
7.4 Transposed Letter Priming effects normalized by subject (ID-TL/Average RT) by Age of Arrival in root transpositions of verbs	148

LIST OF TABLES

Table Number	Page
2.1 Templatic morphology: Hebrew Example	12
2.2 Templatic morphology: Arabic Example	13
2.3 Hebrew Verbal Templates	15
2.4 Arabic Verbal Templates	15
4.1 Stimuli for Study 1-Experiment 1: Root Transpositions in Nouns	62
4.2 Prime times for target words in Experiment 1. Priming as compared to unre- lated.	64
4.3 Stimuli for Study 1-Experiment 2: Template Transpositions in Verbs	67
4.4 Mean RTs for target words in Experiment 2. Priming as compared to unrelated.	68
4.5 Average difference in RT between 6 letter initial condition and other conditions.	69
4.6 Stimuli for Study 1-Experiment 3: Root and Template Transpositions in Nouns	71
4.7 Mean RTs for target words in Experiment 3. Priming as compared to unrelated.	72
4.8 Average difference in RT between 6 letter initial condition and other conditions.	73
4.9 Stimuli for Study 2-Experiment 1: Root Transpositions in Nouns vs. Verbs .	77
4.10 Mean RTs for target words in Experiment 1. Priming as compared to unrelated.	80
4.11 Stimuli for Study 2-Experiment 2: Root and Template Transpositions in Nouns vs. Verbs	82
4.12 Mean RTs for target words in Experiment 2. Priming as compared to unrelated.	83
4.13 Stimuli for Study 2-Experiment 3: Template Transpositions in Verbs	85
4.14 Mean RTs for target words in Experiment 3. Priming as compared to unre- lated. P values obtained from logged reaction times	86
5.1 Stimuli for Experiment 1: Masked Sounds and Environments	96
5.2 Stimuli for Experiment 2: Masked Sounds and Environments	100
6.1 Summary of ERP and MEG Studies Investigating Derivational Components	109
6.2 Participants' Use of Hebrew on Average	113
6.3 Stimuli: Examples for Each Condition	114

6.4	Summary of Behavioral Results	118
7.1	General Subject Info: Age of acquisition, age of arrival in Israel	135
7.2	Stimuli with Transposed Root Letters	136
7.3	Reaction and prime times for target words in Experiment 1. Priming as compared to unrelated.	138
7.4	Reaction and prime times for target words in Experiment 2. Priming as compared to unrelatd	140
7.5	General Subject Info for 26 Subjects on Root Transpositions in Nouns: Age of acquisition, age of arrival in Israel	142
7.6	General Subject Info for 35 Subjects for Root Transpositions in Verbs: Age of acquisition, age of arrival in Israel	143

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Chapter 1

INTRODUCTION

1.1 Chapter goals

This chapter is an overview of the dissertation. It lays out the content of the different chapters. It also presents the main research questions addressed therein.

1.2 Dissertation Goals and Research Questions

This dissertation investigates the role of morphology in word recognition in Hebrew as a templatic language. Much of the research on word recognition has focused on concatenative languages in which morphological complexity is manifested through affixation and in which stems are monomorphemic. By contrast, stems in templatic languages are inherently complex, consisting of roots and templates (excluding a limited number of concatenative borrowings). During word recognition, affixed words in concatenative languages are thought to undergo decomposition into composite morphemes (e.g. Taft 2004); similarly templatic words in templatic languages are proposed to be decomposed into roots and templates Frost (2012).

Results of previous studies suggest that the root plays a particularly important role in noun word recognition in reading. Velan and Frost (2009) [Hebrew] and Perea et al. (2010) [Arabic] have demonstrated that readers are sensitive to root letter position (roots with transposed letters do not prime). By contrast, in concatenative languages, readers are not sensitive to unaffixed words with transposed letters (words with transposed letters do prime) (e.g. Duñabeitia et al. 2007). Similarly, readers of templatic languages are not sensitive to transposed letters in borrowings from concatenative languages (Velan and Frost,

2011). These results have been taken as evidence of letter position flexibility in visual word recognition for concatenative words, but not templatic ones. Transposition studies have thus far been limited to roots, however, and template letter flexibility has not been explored. In this dissertation I perform a series of transposition studies in order to fill several crucial gaps in the existing research.

The first goal of this dissertation is to investigate whether the role of the root and template differ in word recognition. In Chapter 4, I look at whether letter position flexibility in reading is different for root versus template morphemes in order to investigate the roles of each of these morphemes in word recognition.

The second goal of this dissertation is to compare the role that roots and templates play across lexical categories. Transposed letter studies in templatic languages have focused on nouns alone and letter position flexibility in verbs has not been explored. Evidence from priming experiments has shown different priming effects for nouns and verbs in templatic languages. In particular, nouns are primed by words with shared roots only, while verbs are primed by words with either shared roots or templates (Deutsch et al. 1998; Frost et al. 1997). The transposed letter priming paradigm provides a further mechanism for investigating the role of the root and template in word recognition in verbs versus nouns. It also addresses the question of whether orthographic neighbors are activated during recognition, as with concatenative languages. This could allow for recognition of words with mistakes, such as in transposed letter priming, provided the transposition is not of noun root letters. I investigate whether letter position flexibility is the same for roots and templates across lexical category in Chapter 4.

The third goal of this dissertation is to answer the question of whether the role of morphology in word recognition is specific only to reading and visual word recognition. Since much of the work examining the role of morphology in templatic word recognition has been in the visual domain, I investigate word recognition in the previously unexplored auditory domain. In particular, I investigate whether there is evidence for a difference in recognizing templatic vs. concatenative words in Hebrew in the auditory domain. I also investigate

whether the root plays an a particularly important role in auditory noun word recognition as it does in visual word recognition (Chapter 5).

The fourth goal of this dissertation is to explore the default reading mechanism in Hebrew for unaffixed words, given that most words are templatic. I do this by comparing processing costs of reading templatic versus concatenative words in Hebrew (Chapter 6).

The fifth goal of this dissertation is to determine whether Hebrew readers have the same reading mechanisms for inflectionally affixed words as readers of concatenative languages. Studies on concatenative languages have shown inflectionally affixed words are decomposed into stems and affixes (e.g. Taft 2004; Leinonen et al. 2009). I investigate whether Hebrew readers show evidence of this decomposition as well and whether it manifests similarly (Chapter 6).

The sixth and final goal of this dissertation is to investigate the acquisition of reading mechanisms of Hebrew by native speakers of concatenative languages. Having established the important role of templatic morphology to word recognition in Hebrew as a templatic language, I investigate whether second language learners utilize this same approach or whether they transfer reading methods from their native language. Previous studies have shown transfer effects from native languages into second languages, particularly in online tasks (e.g. Sabourin et al. 2014). The goal of this study is to determine whether the role of morphology in word recognition transfers from the concatenative first language or whether proficient readers acquire the native Hebrew reading mechanisms. Furthermore, I explore whether this is dependent on age of acquisition (Chapter 7).

The main research questions of this dissertation are as follows:

- 1) What is the role of the root and template in templatic word recognition and does this differ for verbs and nouns?
- 2) Does the role of morphology in word recognition differ depending on modality: visual versus auditory?
- 3) Is the default mechanism for word recognition of unaffixed words in a templatic language decomposition?

4) Is there evidence of decomposition of inflectionally affixed words into stems and affixes as with concatenative languages? If so, do the costs of this decomposition manifest similarly to concatenative languages?

5) What are the implications of the findings of this dissertation to theoretical predictions and word recognition models?

6) Is there evidence of transfer of reading mechanisms from native concatenative languages to Hebrew as second language by proficient readers? Does this correlate with age of acquisition or arrival?

1.3 *Dissertation Outline*

This section provides an outline of the chapters of the dissertation.

In Chapter 2, I begin with an introduction to the Semitic language branch. This overview provides a background for the genetic relationship between Semitic languages, which share the templatic morphology that is being investigated in the dissertation. In the second part of the chapter, I describe the morphological structure of Hebrew and Arabic as two templatic Semitic languages. The description includes information about the root and template as well as lexical categories, affixation and other grammatical and morphological components, which may play a role in word recognition. I provide illustrations for both Arabic and Hebrew to give a clear picture of the grammatical parallels between these templatic languages.

I then provide background for visual and auditory word recognition, focusing particularly on the role of morphology. The review includes studies on templatic and on concatenative languages and points out the processing differences observed between these. This chapter also presents reading and auditory models of word recognition as well as a time-course of the steps involved (Chapter 3).

In Chapter 4, I present two studies investigating the role of morphology in visual word recognition. In the first study, letter position flexibility is compared for root versus template morphemes. The second study compares the role of the root and template in recognition

of nouns versus verbs. The results of these studies show that roots and templates differ in letter position flexibility and in the roles they play in verbs versus nouns.

Chapter 5 investigates word recognition in the auditory domain. Using the phoneme restoration technique, this study explores differences between recognition of concatenative and templatic words. In addition, this technique is used to discover whether the role of the root in nouns is just as important to auditory word recognition as it is to visual word recognition. In both experiments, auditory word recognition is shown to pattern with visual word recognition, suggesting a similar role of morphology in this domain.

In Chapter 6, the ERP (event-related potential) paradigm is used to compare reading templatic words and concatenative borrowings. Greater processing costs are shown for reading concatenative words, suggesting that stem decomposition is the default mechanism in Hebrew word recognition. Additionally, it investigates reading of (inflectionally) affixed words in a templatic language. As with concatenative languages, higher processing costs are observed for reading affixed words in line with decomposition of these words into stems and affixes.

While the other studies in this dissertation focus on native Hebrew speaker reading, the study in Chapter 7 investigates reading in Hebrew as a second language. Transfer effects for reading mechanisms are observed from the native concatenative language to Hebrew as a second language. These effects do not correlate with either age of acquisition or age of arrival.

The final chapter is a conclusion chapter in which I return to address the research questions raised in this introductory chapter.

Chapter 2

INTRO TO SEMITIC MORPHOLOGY: EXAMPLES FROM HEBREW AND ARABIC

2.1 Chapter goals

The goal of this chapter is to provide a background of Semitic Morphology. I begin by giving a brief history and background on the Semitic language branch of the Afro-Asiatic family (Section 2.2). I then introduce the morphological (Section 2.3) and writing systems (Section 2.3.4) of Hebrew and Arabic. Finally, I summarize some of the main theoretical descriptions of the Semitic morphological system (Section 2.3.4).

2.2 Semitic Language Branch

The Semitic language branch (which includes Arabic and Hebrew) is one of six branches of the Afro-Asiatic family with Omotic, Cushitic, Berber, Chadic and Old Egyptian (Lewis et al., 2009). The unique morphological system of Semitic languages, laid out in Section 2.3 below, makes them especially important to understanding word recognition across languages and universally. This section serves to briefly introduce the Semitic language family.

2.2.1 Semitic Language Trees

According to Ethnologue (Lewis et al., 2009), there are currently 77 Semitic languages in the world (35 of these are Arabic languages). While some of these languages (e.g. Hebrew and Arabic) have retained a productive Semitic morphology, the Semitic morphology of other languages such as Maltese (Hoberman and Aronoff, 2003; Perea et al., 2012) is no longer productive. As discussed in Chapter 4, the productivity of the morphological system may play an important role in the processing of the language.

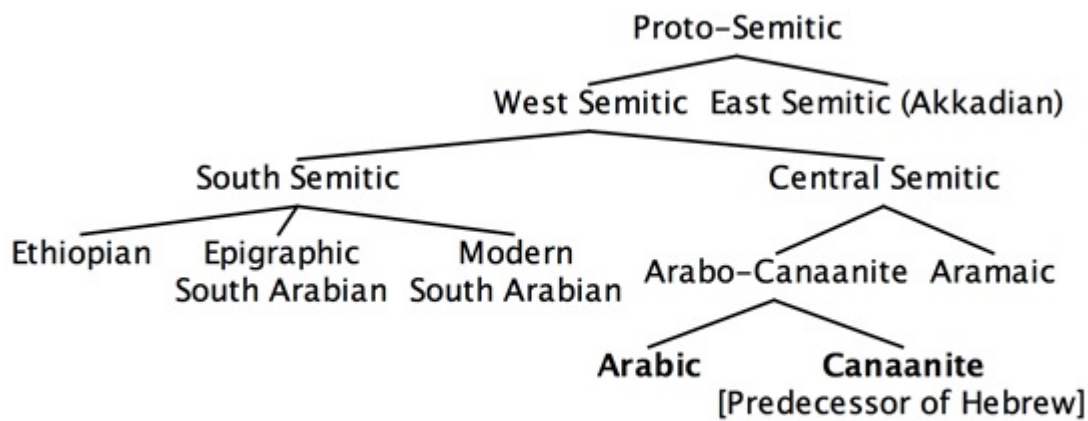


FIGURE 2.1: Adapted from Hetzron (1976) Classification of Semitic languages

Figure 2.2.1 illustrates one common approach to the structure of the Semitic family tree by Hetzron (1976). This classification is made based on shared morphological features of the languages. In contrast to previous approaches, which used solely geographical features, Hetzron's approach relies on linguistic features. While there is still some debate on the classification of languages in the Semitic language branch, I take this more modern approach here to give a general idea of the Semitic branch make-up. In this approach, there are three main sub-branches: South Semitic languages, including Ethiopian and Arabian languages; East Semitic languages including Akkadian languages and finally the central Semitic, including Aramaic, Arabic and Canaanite. According to this classification both Arabic and Hebrew stem from the Central Semitic Branch. Modern Standard Arabic is a descendant of Classical Arabic which is the Arabic represented on the tree, while modern Hebrew stems from Ancient Hebrew, which is a Canaanite language.

Ancient Hebrew differentiated into its own language around 1200 BCE and was followed by Standard Biblical Arabic from about 8th-6th centuries BCE and then Medieval or Rab-

binic Hebrew subsequently. The origin of Modern Hebrew is described further in 2.2.4. Classical Arabic emerged some time later, around 250-330 CE. The emergence of Modern Standard Arabic is described in Section 2.2.3.

2.2.2 Background of Modern Hebrew and Modern Standard Arabic as Semitic Languages

The majority of research to date on word recognition and reading in Semitic languages is on Modern Standard Arabic and Modern Hebrew (e.g. Perea et al. 2008; Velan and Frost 2011, 2009, 2007). In order to give a better understanding of these languages and their histories, I give a brief background of each of them.

2.2.3 Modern Standard Arabic

Modern Standard Arabic was created in the 19th century, at a time when the various regional dialects of Arabic had already become different enough to no longer all be mutually intelligible with one another. Classical Arabic is a written language and was initially similar to the dialects of spoken Arabic. However, around the 7th century Classical Arabic and the spoken dialects began to diverge as the Arabic speaking empire spread. While these dialects continued to change, Classical Arabic remained the same, mostly for religious reasons as this was the language of the Qur'an (Blau, 1981). As a result there was no shared mutually intelligible language across the Arabic speaking countries aside from the unchanging classical Arabic. In the 19th century, as the Ottoman Empire was falling apart and European Imperialism brought modernization to these countries and a stronger sense of nationalism, the need arose for a shared Modern Arabic. This Arabic included Modern and European concepts, which Classical Arabic did not have. At a time when printing presses were becoming popular and literacy rates were rising, it allowed for modern Arabic books and newspapers to be published to reach the entire Arabic speaking world.

Several Arabic Language Academies were formed including the Academy of the Arabic Language in Damascus and the academies of Iraq, Cairo and Jordan in order to ensure that this new language maintained its classical structures (Blau, 1981; Versteegh, 1997).

These academies worked to modernize the language, with the specific goals of maintaining its Semitic nature (keeping it from Europeanization) and its closeness to Classical Arabic (avoiding dialectal influence). While the spoken Arabic dialects were living languages, this new Modern Standard Arabic Dialect was formed from a language that had not been spoken in centuries. Thus, this was in a sense a rebirth of a language (or at least a form of it) whose only use had been for religious purposes, similar in some ways to Latin.

Modern Standard Arabic is a revived language; however it has no speakers for whom it is a native language. Instead, there exists a diglossia across the Arabic speaking world. Spoken dialects are used in the home and in most interactions and are acquired as first languages. Modern Standard Arabic (MSA) is taught to children in school and is used primarily in writing as well as in particular spoken settings which are especially formal or which are intended to reach the entire Arabic speaking world, such as news broadcasts. It also serves as a lingua franca for speakers of different Arabic dialects, particularly those that differ significantly. Interestingly, even in more casual writing settings, MSA - not some dialectal form - is typically used, although people's adherence to grammatical rules may vary (Blau, 1981). Even in a context in which MSA is used, speakers often codeswitch between Modern Standard and their respective dialects.

The diglossia between the language used for writing and the one used for speaking poses a challenge for investigating readers word recognition mechanisms. Studies looking at Arabic reading have focused on Modern Standard Arabic as it is primarily used for writing in all Arabic countries. This means, however, that the language being investigated is not the participants' native language. Even when studies are set in a spoken dialect, the testing environment is not natural, given that most writing is done in MSA. Furthermore, while the morphology of MSA is also a templatic one, it does differ from that of spoken dialects.

Hebrew, on the other hand, is a Semitic language in which the written and verbal systems are the same. For this reason, it serves as an excellent comparison to Arabic. In the following section I give an account of the Modern Hebrew that is spoken today and the subject of this dissertation.

2.2.4 Birth of Modern Hebrew

Hebrew has gone through several periods of change and innovation prior to the development of the current form of Modern Hebrew spoken today. The earliest written works of Ancient Hebrew date back to the 10th century B.C.E. (William M. Schniedewind, 2013), while the language itself likely separated from its predecessors centuries prior. The next stage of Hebrew, Biblical Hebrew, is documented through biblical texts. Due to the subsequent exile of the Israelites from Israel, biblical Hebrew was the last truly spoken form of Hebrew until Modern Hebrew emerged. However, due to the religious tradition of prayer and bible study conducted in Hebrew, the language continued to develop into a Middle or Rabbinic Hebrew. This was the last innovation to Hebrew until Modern Hebrew was born in the end of the 19th, beginning of the 20th century.

Hebrew went through a renaissance that is in many ways similar to that of MSA. It had not been used as a mother tongue for about 17 centuries when a modern version suddenly emerged (Blau, 1981). As with Arabic, Modern Hebrew (Hebrew henceforth) was mostly revived in the 19th century, while contemporary plays and newspapers date back as early as the 16th century (Sáenz-Badillos and Elwolde, 1996). The revival also came at a time of nationalism and the popular use of printing presses. While the first dictionaries were printed in the late 19th century, it was in 1922 that Hebrew became one of the official languages of a country, at the time Palestine. As with Arabic, a Language Academy was formed in order to ensure the language maintain its connection with its previous versions. Unlike MSA, however, Hebrew was developed from two older languages, Biblical and Middle (or Mishnaic/Rabbinical) Hebrew.

Today, Hebrew is a spoken language, a native language to millions of speakers, and one of the official languages of the State of Israel. Hebrew has two dialects: Standard Hebrew and Oriental Hebrew (Mizrahi). These dialects are mutually intelligible and vary primarily in phonological and phonetic respects. Standard Hebrew's phonology has adapted to be closer to that of European languages such as Yiddish, while Oriental Hebrew shares more

of its phonology with Semitic languages, primarily Arabic. Each of these dialects carries some overt prestige. While the Standard dialect carries overall prestige, the Oriental dialect is often desired for news casters and other professional speakers and its pronunciation is considered more ‘correct’ and closer to that of ancient Hebrew. In contrast to MSA, Hebrew is used in every sphere of life: from written to cultural to casual speech. It is also the native language of many Jewish Israelis.

2.3 Morphological Structure: What makes up a Semitic word

In this section I introduce the morphological structure of Semitic language using Hebrew and Arabic as examples. These descriptions are reflective of the traditional grammarian approach to Semitic morphology and allow for an easier introduction to the morphology of these languages. Other theories of Semitic morphology are discussed separately in Section 2.4. The structure of Arabic languages is very similar to the structure of Hebrew, as are the structures of many other Semitic languages. In order to show the similarities in morphology between Hebrew and Arabic as Semitic languages, I give an illustration of the verbal and nominal systems of Hebrew and Arabic in parallel in Section 2.3.2. While the work of this thesis is focused on Hebrew, I expect many of the processes to extend to Arabic and other Semitic languages due to the similarity of the morphological systems outlined here.

2.3.1 The Root and the Morpheme

Semitic morphology differs from the morphology of other languages in two main respects. First, morphemes are combined differently in Semitic languages than in other (concatenative) languages. Morphemes are the smallest units of meaning or function such that more than one can make up a word (e.g. the word *cats* has two morphemes *cat* and plural marker *-‘s’*). In concatenative languages such as English, Basque, or Japanese, morphemes are appended one onto another in a linear fashion (as in the *cats* example the *-‘s’* is appended to *cat*). Even in cases of infixation, one morpheme is cut in a particular place and a second one is inserted. This is not the case for templatic languages like Hebrew, Arabic and other Semitic

languages where morphemes can be fused non-linearly. In addition, while in non-Semitic languages an un-affixed word typically consists of a single morpheme (e.g. the word *table* can not be broken into any smaller parts), typical Semitic words are complex, consisting of more than one morpheme.

A Hebrew word (e.g. HiTKaTeV¹ *to correspond*) can be broken into a three consonant root² (**K.T.V.**) and a template with place holders for the root letters (HiTR1aR2eR3). Words are formed by inserting root consonants into the placeholders in a template. Depending on the template, root letters may end up in a consecutive order or may be separated by template letters (e.g. HiTKaTeV versus **KTIV**). Templates can be combined with different roots (HiTRaXeK *to distance oneself*) and contain information about part of speech and other factors such as (in this case) reflexivity. See Table 2.1 for illustration. As with concatenative languages, Hebrew words can be affixed by appending a prefix and/or a suffix. Affixation serves a variety of functions in Hebrew including tense, number, gender and person markers (see Table 2.1) as well as definite and infinitival markers.

TABLE 2.1: Templatic morphology: Hebrew Example

	Transliteration	English Gloss
Root	K.T.V.	<i>writing</i>
Template	H-i-TR1-a-R2-e-R3	<i>reflexive verb</i>
Word	H-i-TK-a-T-e-V	<i>to correspond</i>
Affix	TI	PAST-SG
Affixed	H-i-TK-a-T-a-V TI	<i>I corresponded</i>

¹I use bold formatting to identify root letters. Capital letters are used for those letters present in the orthography and lower case letters are used for those omitted.

²Roots typically consist of three consonants, but may also consist of four letters and can include letters that are placeholders for vowels.

Arabic words similarly consist of a root and template as illustrated in Table 2.2 using the root **D.R.S.** *to study*. When combined with the causative template **R1aR2R2aR3a**, it creates the word **DaRRaSa** meaning *to teach* (i.e. to cause someone to study). Words in Arabic are also affixed for inflectional morphology. As shown in Table 2.2, the ‘TU’ suffix marks past tense singular and third person. Thus, through affixation, it is possible to create the word **DaRRaSTU** *he studied*.

TABLE 2.2: Templatic morphology: Arabic Example

	Transliteration	English Gloss
Root	D.R.S.	<i>study</i>
Template	R1-a-R2 R2-a-R3-a	<i>causative verb</i>
Word	D-a-RR-a-S-a	<i>to teach</i>
Affix	TU	PAST-SG
Affixed	D-a-RR-a-STU	<i>he taught</i>

There are Hebrew words that are not templatic, meaning they do not consist of a root and morpheme. These are often ancient borrowings from concatenative languages that have entered the language without adopting the morphological system. While these make up a minority of words, some of these borrowings are fairly prevalent, such as the word for ‘table’ [fulxan]. Such words behave like any other concatenative words in that they can take affixation and their stems consist of a single morpheme.

2.3.2 Templatic Morphology

Verb Templates

Hebrew verbs are created with the help of a closed class of seven template forms. Similarly, Arabic verbs fall into a closed class of ten template forms, nine of which are productive.³ Template VIV in Arabic is mostly used for colors and is not very productive. In both sets of languages, verbs are formed by combining roots and templates. Many roots can only be combined with a subset of the templates (e.g. a passive template cannot be combined with certain intransitive roots such as ‘run’ or ‘swim’). In contrast to verbs, there are around 100 noun forms in Hebrew, varying in level of productivity. Verbs are a good setting for an introduction to Semitic morphology, given their limited number of forms and the demonstrable parallels among morphological systems in Semitic languages. In order to demonstrate, I introduce the verbal system of Hebrew and Modern Standard Arabic.

In Hebrew grammar, templates are represented using a formalism in which the three root letters are substituted with the letters P (sometimes pronounced [f]), ʕ, and L, where P represents the first letter, ʕ the second and L the third. Similarly, in Arabic, the formalism uses the letters F, ʕ, and L to represent the root letters. As can be seen in the IPA column of Tables 2.3 [Hebrew] and 2.4 [Arabic], this allows for a pronounceable generic version of each template that can then be replaced with a real root to form an actual word.

The examples in Tables 2.3 and 2.4 in Hebrew and Arabic serve to illustrate the role of both the root and the template in the Semitic word. While the root, in these cases the Semitic K.T.V. root found in both Hebrew and Arabic, carries the main meaning, the templates also give information. For instance templates 2, 5 and 6 in Hebrew usually give a passive meaning and templates V, VII, VIII in Arabic typically have a passive or ‘change of state’ meaning, as illustrated by the examples.⁴

Noun Templates

³Arabic languages such as Quaranic Arabic can have up to 15 forms, however the last 5 are very rare and not productive.

⁴While the numbering of Arabic templates is somewhat standard and used for reference especially in second language learning textbooks, the Hebrew numbers and ordering assigned here are not standardized and in this dissertation are used for easy reference. Hebrew templates are mainly referred to by the formalism represented in the second and third columns except for the first template which is also called ‘Kal’ meaning simple.

TABLE 2.3: Hebrew Verbal Templates

	Template	IPA	Example	Translation
1	P(a)ʕ(a)L	[paʕal]	KaTaV	<i>‘wrote’</i>
2	N(i)ʕA(a)L	[niʕal]	NiKTaV	<i>‘was written’</i>
3	P(i)ʕ(e)L	[piʕel]	KiTeV	<i>‘engraved’</i>
4	H(i)P ʕ(i)L	[hiʕil]	HiKTiV	<i>‘dictated’</i>
5	P(u)ʕ(a)L	[puʕal]	KuTaV	<i>‘was engraved’</i>
6	H(u)Pʕ(a)L	[huʕal]	HuKTaV	<i>‘was dictated’</i>
7	HiTP(a)ʕ(e)L	[hitpaʕel]	HiTKaTeV	<i>‘corresponded’</i>

TABLE 2.4: Arabic Verbal Templates

	Template	IPA	Example	Translation
I	FaʕaLa	[faʕala]	KaTaBa	<i>‘wrote’</i>
II	FaʕʕaLa	[faʕʕala]	KaTTaBa	<i>‘made’</i>
III	FAʕLa	[fa:ʕala]	KATaBa	<i>‘wrote’</i>
IV	AFʕaLa	[a:faʕala]	AKTaBa	<i>‘dictated’</i>
V	TaFaʕʕaLa	[tafaʕʕla]	TaKaSSaRa	<i>‘smashed’</i>
VI	TaFAʕaLa	[tafa:ʕala]	TaKATaBa	<i>‘corresponded (mutual)’</i>
VII	INFaʕaLa	[infaʕala]	INKaTaBa	<i>‘subscribed’</i>
VIII	IFTaʕaLa	[iftaʕala]	IFKaTaBa	<i>‘copied’</i>
VIV	IFʕaLLa	[ifʕalla]	IFHaMaRRa	<i>‘turned red’</i>
X	ISTaFʕaLa	[istaʕala]	ISTaKaTaBa	<i>‘asked to write’</i>

Hebrew and Arabic nouns, like verbs, consist of roots and templates. However, in contrast to verbs, nouns do not have a limited closed class of templates. In both Hebrew and Arabic, there are at least one hundred noun templates of varying productivity which can be combined

with roots to create nouns. There are also productive mechanisms for noun creation. I give a few examples of the latter below.

Both Arabic and Hebrew have a process for noun formation from verbs creating verbal nouns. This process follows the templatic system in that there are different verbal noun template forms for different templates. For instance, in Arabic, verbal nouns for Template II verbs ([faʕʕala]) are of the form [taffil]. Thus the verbal noun for the verb [DaRRaSa] *to teach* is then [TaDRIS] meaning *teaching*. Similarly, in Hebrew, for example, the verbal noun for template [hiffil] (Table 2.3) is [haffala]. So, the verbal noun of the verb [HiZMIN] *to invite* is [HaZMaNH] *invitation*.

In Hebrew, there are also a productive set of affixes for noun creation analogous to English gerunds created with the -‘ing’ affix. These include -‘un’ and -‘ut’ suffixes among others and are used productively in noun formation.

2.3.3 Inflectional Morphology

This section briefly introduces the inflectional morphology of Hebrew and Arabic as Semitic languages.

Nouns: Gender

Both Hebrew and Arabic nouns have binary grammatical gender: masculine or feminine. Animate nouns reflect the gender of the referent and can typically be declined as masculine or feminine, while inanimate nouns have grammatical gender. Feminine gender is marked, while masculine is the default. For instance, in Arabic, the word for a male dog is [kelb], while a female dog is [kelba]. Similarly, the Hebrew word for a cat is [xatul] and for female cat is [xatula].

In MSA, feminine nouns typically end in -‘at’, -‘a’ or -‘a’. Feminine marking varies somewhat across dialects, however the -‘a’ ending (as illustrated in *female dog above*) is a fairly typical one across dialects. In Hebrew feminine gender in nouns is marked by -‘a’, -‘it’, or -‘et’. While the majority of feminine nouns are marked, there are exceptions in both Hebrew and Arabic, where feminine nouns have unmarked endings (e.g. [ʃams] *sun* in Arabic

and [kos] *glass* in Hebrew).

Nouns: Number

In both Hebrew and Arabic plural marking on nouns is done through affixation. Plurals agree in gender with the noun. Hebrew feminine plural nouns typically end in -‘ot’, and masculine nouns in -‘im’. Arabic plural nouns in turn are typically affixed -‘iin’ for male and -‘aat’ for female. There are exceptions to these rules. In Arabic there is a class of nouns, ‘broken plurals’, made plural, made plural through vowel alternation rather than affixation (e.g. [KiTAB] *book* -> [KuTuB] *books*). In Hebrew, affixes are necessary but there are classes of nouns that undergo vowel alternation as well.

In addition to plural marking, both Hebrew and Arabic utilize a dual marker suffix, -‘ayim’ in Hebrew and -‘een’/‘ayn’ in Arabic. In order to refer to two of something, the noun is marked for dual rather than plural. Over time this marker has become limited in its productivity in both spoken Arabic dialects and in Modern Hebrew. In Hebrew, the dual marker is primarily used for body parts, clothing, and time-periods. Similarly, in spoken Arabic dialects, dual is primarily used for body parts and time periods. Dual is, however, used productively in MSA.

Nouns: Case Endings and Definite Markers

As with dual markers, case endings are not very productive in either spoken Arabic dialects or in Modern Hebrew. They are however present in MSA, at least in principle. In practice, they are reported to be often underused or misused (Hetzron, 1998).

In MSA, nouns are marked with endings for nominative (-‘un’), accusative (-‘an’) and genitive (-‘un’) cases. In contrast, in spoken Arabic, only Arabian Bedouin and Yemenite dialects have case endings and even these are limited in function. Bedouin dialects have kept certain features of Classical Arabic due to their isolation at times when the Bedouin lifestyle was nomadic and had little regular contact with other languages or dialects.

Hebrew and Arabic are marked for definiteness through a prefixed definite marker onto the noun itself. There is no marker for indefinite nouns (such as the determiner ‘a’ in English). In Hebrew, definite nouns are marked with the prefix ‘Ha’- and in Arabic with

‘El’-.

Verbs: Tense, Mood, Person and Infinitival Marking

Verbs in both Hebrew and Arabic are inflected for a variety of categories. In Hebrew verbs can be imperative, participial/present, past and future. This is marked through a combination of prefixes and suffixes. Within each category nouns are inflected by person and gender. Hebrew also has infinitival verbs marked with the prefix ‘l’- meaning *to*, which do not have further inflection.

Similarly, MSA verbs are inflected for tense, mood and aspect categories including perfect (present), imperfect, indicative, subjunctive and jussive, past and future. Dialects of spoken Arabic have kept some of these categories and differ between themselves in how these are applied. As in Hebrew, verbal inflection is marked through suffixes and/or prefixes, which are in turn inflected for person and gender. MSA does not have an infinitival form.

Agreement

In Arabic, verbs agree with the subject in person, number and gender. Adjectives agree with the head nouns in definiteness, gender and number. In Hebrew, as in Arabic, past and future tense verbs agree with the subject in person, number and gender. In present tense, Hebrew nouns agree with the subject in number and gender only. As in Arabic, Hebrew adjectives agree with their nouns in definiteness, gender and number.

2.3.4 Morphology and the Writing System: Reading without Vowels

The Hebrew writing system, like the MSA writing system, is written largely without vowels. Vowel information can be represented through a set of diacritics; however these are primarily used for texts for children learning to read or for foreign words. For instance in the word HiTKaTeV [hitkatev], all the vowels appearing in lower case are not written and the word would appear as HTKTV. There are cases in which some vowels are represented in writing (e.g. in the word KTIV [ktiv]), however the majority of vowels are not written. In this dissertation, I will represent any vowels omitted in writing with lower case letters.

This near omission of vowels in the writing systems serves as a potential confound for

looking at effects of morphology on word recognition. The fact that the most studied languages with Semitic morphological systems (Hebrew and Arabic) also largely omit vowels in writing can make it difficult to parse out the morphological effects from the orthographic ones. In my research on written Hebrew, discussed in Chapter 4, I strive to address this issue. For further discussion on this in both this dissertation and previous literature, see Chapter 4.

2.4 Semitic Morphology: Theoretical Frameworks

A traditional grammarian approach to Semitic morphology (e.g. Versteegh 1997) is the one laid out in Section 2.3.1. However, in more recent years, a variety of other theories have emerged. In this section I introduce several of the most prominent of these and then relay the approach adopted by this thesis.

2.4.1 Autosegmental Approach: The Three Morpheme Tier

Stemming from the Goldsmith and Club (1976) framework of Autosegmental Phonology, (McCarthy, 1981, 1979) developed a three tier approach to Semitic morphology. This approach involves a root node with feature matrices associated with this node in contrast to competing approaches at that time in which morphemes were separated by boundary lines.

As in the traditional approach, McCarthy argues for the root as the base morpheme. Support for this stems from several generalizations across Semitic languages. First of all, related words have different templates and only the root in common, as evident from the examples in Tables 2.4 and 2.3. Secondly, McCarthy refers to a language game played in Bedouin Hirazi Arabic in which players switch the order of only root consonants, keeping the position of other consonants unchanged. The existence of this game gives support for the grammatical or psychological reality of the root as its own entity. Thirdly, there are certain phonological co-occurrence constraints on root letters including the Obligatory Contour Principle (OCP) preventing co-occurrence of consecutive root letters and letters sharing certain properties. Finally, there are phonological assimilation rules that depend on the interaction between

roots and templates.

McCarthy argues that, along with the root, there are two other morphemes that make up the un-affixed Semitic word: the prosodic template (e.g. CVCVC) and the vocalic pattern consisting of the vowels themselves as illustrated in Figure 2.3. This extra division into prosodic template and melody allows for accounting for generalizations particular to the melody tier. For instance, in Arabic, there are no [i] followed by [u] melodies or melodies beginning in [u].

This theory not only accounts for phonological patterns that affect different tiers, but also for interactions among tiers. For instance, when a pattern calls for three root letters (as patterns do), but the root only has two letters, McCarthy's account predicts which of the two root consonants geminates to fill the gap left in the prosodic template tier. In a traditional approach, this type of root would be seen as having two of the same consonant instead, missing out on the generalization and predictive power of the McCarthy approach.

Overall, McCarthy's approach has explanatory power when it comes to phonological rules and patterns in Semitic morphology. In the context of this dissertation, however, there is little psychological support for the actual storage of Semitic words along the three tiers. I will further discuss processing evidence in Chapter 2, where I provide background for this. At this point, I think it is important to note that whether or not words are stored as three separate morpheme tiers, McCarthy's approach certainly lends insight into possible computations on the phonological level. This would not necessarily be at odds with a traditional grammatical approach of just two morphemes, a root and template being stored separately in the brain. Further discussion of this is outside the scope of this dissertation, however it is certainly an area for processing research.

2.4.2 Generalized Templatic Theory GTT

Following McCarthy (1979, 1981), Ussishkin (2006, 2005) developed an extended theory of Semitic morphology called the Generalized Templatic Theory. As with McCarthy's theory, phonological rules play an important role in the morphology in GTT and both make use of

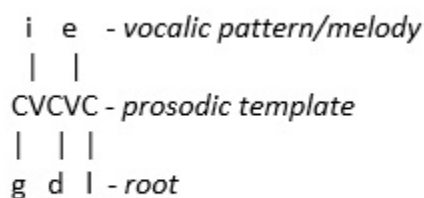


FIGURE 2.2: Three Tier Structure: word *gidel*, adapted from McCarthy (1985, 1979)

Autosegmental Phonology. However, Ussishkin's approach additionally makes use of Optimality Theory (OT) (Prince and Smolensky, 1993) and is largely based in that framework. In order to introduce the GTT model, I focus primarily on the aspects of the model that are useful to comparing to other models and to applying it to the research in the dissertation, rather than describing particular formalisms. However, I briefly introduce OT theory below to illustrate the framework in which this model is situated.

Optimality Theory, initially developed by Prince and Smolensky (1993), is a formalism in which grammatical features of a given language are expressed as conflicting Universal constraints, which are ranked differently for each language. In this framework, all language input is initially possible for any given language and is generated at the GEN (generator) stage. The possible inputs then go through a CON (Constraints) filter, which is specific to the language which consists of a language appropriate ordering of these constraints. Finally, the optimal input, i.e. that which least violates highly ranked constraints in that language, is chosen in the EVAL (evaluation) stage. In this way language-specific output is produced from a set of Universal constraints. Thus, in contrast to McCarthy, who formulated his theory of Semitic Morphology in Autosegmental Phonology, operating on rules, Ussishkin's approach operates on a constraint hierarchy.

Perhaps the most unusual and controversial aspect of Ussishkin's approach is that the root is not the morphological base of Semitic languages. Instead the stem (root+template)

serves as the minimal morphological unit and basis of affixation. Words are then created not through the joining of a root and template, but rather through alternations in the stem. The basic word in both Hebrew and Arabic is equivalent to the first form root and template combination (see the first template in Tables 2.3 and 2.4) respectively. New words are created through melodic overwriting and consonant affixation where an affixed melody can overwrite an existing one.

In defense of his position of whole stem processing, rather than parsing into root and morpheme, from a psychological standpoint, Ussishkin cites studies of other languages that reflect whole word processing of derived and sometimes even inflected forms (e.g. De Jong IV et al. 2000; Clahsen 1999). While, there are certainly studies that show whole word processing for affixation, I would argue that at this point there is far more evidence for at the very least dual route processing where parsing into constituent morphemes is an option (e.g. Grainger and Ziegler 2011). However, I will leave the remainder of this discussion for Chapter 3 where I discuss studies on processing. At this point, I will note that as with McCarthy theory, Ussishkin's GTT contributions may serve as more informative in terms of allowing analysis of Semitic morphology in a phonological framework (in this case OT) than reflecting a psychological reality of processing.

2.4.3 Etymons

One final approach to Semitic morphology which I review here is the Etymon approach, most recently argued by Boudelaa and Marslen-Wilson (2001), originally put forward by Bohas (1997, 1999). They argue that in the traditional approach of a root and morpheme or even an Autosegmental Approach with three tiers (Section 2.4.1) a certain element of generalization is missed. Namely, while the majority of scholars treat the root as consisting of three consonants, there is in fact evidence of a root being composed of just two etymons instead.

Boudelaa and Marslen-Wilson (2001) explain that their problem with previous approaches is two-fold. First of all, like McCarthy and Ussishkin, they argue against taking the tradi-

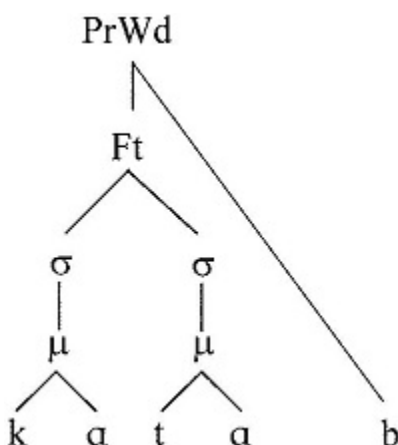


FIGURE 2.3: Adapted from Ussishkin (2005), illustrates prosodic word in GTT with the word *katab*

tional grammatical approach, in which templatic morphology consists of roots and templates. They claim that this approach does not account for apparent patterns in the conjugations of the different forms. Second of all, they argue that roots are too narrow of a base morphological unit. To illustrate this, they provide the following example of a set of words in Arabic: [batta] *cut off*, [batara] *sever*, [balata] *sever*, [bataka] *separate* and [sabata] *cut-down*. If this group of words is approached from the perspective of three-letter roots, they seem unrelated despite their apparent phonological and semantic similarity. However, with the etymon approach, their similarity can be accounted for by them all sharing the [bt] etymon.

The ability to form word groups is further extended with the concept of etymon allomorphy. That is the two letters of an etymon can at times switch places. Furthermore, etymons can at times share features e.g. [+labial], rather than letters or sounds. Finally, as with roots, words with the same etymon need to be semantically related. It is important to note here that both Brohan and Boudela and Marslen-Wilson focus specifically on Arabic and it is not clear how their examples would transfer over to Hebrew or other Semitic languages.

From a psychological processing perspective, Boudelaa and Marslen-Wilson (2001) includes a study looking at morphological priming by words sharing etymons and not roots,

which shows evidence in the favor of etymons. They argue that the results of previous studies looking at roots alone are actually reflecting this more fine-grained etymon processing. In this dissertation, I do not directly compare etymons and roots and therefore can speak little to the distinction between them and the roles they may play in Semitic processing. However, as Boudelaa and Marslen-Wilson (2001) themselves point out, previous studies looking processing with roots and morphemes are still able to reflect the processing of Semitic words. For this reason, I argue that my findings are not in direct competition with etymon theory, but would rather need to be evaluated in terms of etymons at some future date.

2.4.4 Current Approach

In this thesis, I will primarily take the traditional grammatical approach to templatic morphology. This approach, as described in Section 2.3.1 above, is still prominent today and assumed in several of the seminal studies of Semitic word recognition including work by Hadas Velan and Ram Frost in Hebrew (e.g. Velan and Frost 2009, 2007). The reason for doing so is that it is most consistent with processing evidence as I will further explain in Chapter 3. At the same time, as I have stated above, it is possible for aspects from various theories to account for the structure of Semitic morphology and I think these need not all be mutually exclusive. In the Conclusion and in Chapter 4, I will further discuss implications of the results of this dissertation for theories of Semitic morphology.

Chapter 3

LITERATURE REVIEW: MODELS OF WORD RECOGNITION AND LEXICAL ACCESS

3.1 Chapter goals

The goal of this chapter is to introduce the current models of word recognition both in reading and in listening with a particular focus to the role of morphology in these. Understanding each of these poses its own unique challenges. In reading, for example, a person must be able to quickly match a sequence of letters to a word.¹ In auditory word recognition, the initial challenge presents itself even earlier, when a listener must be able to distinguish individual words in the speech stream.

3.2 Role of Morphology in Visual Word Recognition

Morphology plays a key role in word recognition. In concatenative languages, morphological processing is evident primarily in words with more than one more morpheme, such as affixed words (e.g. Taft and Forster 1975). Evidence from templatic languages with their inherently complex words suggests that in these languages morphology (nearly) always plays a role in word recognition (e.g Velan and Frost 2011). This section introduces the evidence from research on the role of morphology in word recognition which should be considered in developing reading models. The remainder of the dissertation continues to explore the role of morphological processing in Hebrew as a Semitic language.

¹Readers additionally face the challenge of matching shapes to letters, i.e. letter recognition, which is a separate problem and is outside the scope of this dissertation.

3.2.1 Evidence for Decomposition into Stems and Affixes

Evidence from existing research suggests that some or all affixed words are decomposed during reading (e.g. Taft and Forster 1975). Here, I briefly introduce some of the evidence for decomposition; reading models for reading complex words are discussed in Section 3.3.3.

Taft and Forster (1976, 1975) [English] used the lexical decision paradigm to compare reading morphologically complex words of different types. When looking at prefixed words, he found that words in which a stem could be both bound and free (e.g. *vent*) took longer to classify since the bound form, as in *invent*, is more frequent than the free form. In addition non-words consisting of real stems and prefixes (e.g. *dejuvinate*) took longer to classify. Similar effects were found with compounds that are non-words; these took longer to classify if the first constituent is a word. Together, these findings provide evidence for decomposition into a stem and affixes or into two stems in the case of compounds. These studies faced criticism due to the lexical decision component and the nature of the stimuli, suggesting that these encouraged readers to adopt a prefix stripping strategy. In a follow-up study, Taft (1981) [English] then used a naming paradigm with all real words in which subjects were asked to say the word and reaction time was measured from presentation to the start of naming. Prefixed and pseudo-prefixed words (e.g. *advance*) with non-productive stems were compared. Participants initiated naming pseudo-affixed stems more slowly, again suggesting that decomposition occurs and that it is a default mechanism.

Morphological decomposition has also been investigated through masked and overt priming. In a masked priming paradigm, Rastle et al. (2004) [English] found that morphological priming occurred with both semantically related morphological primes (cleaner-clean) and pseudo-morphological primes (corner-corn), in contrast to non-morphological form related primes such as (brothel-broth). In another masked priming experiment, Longtin and Meunier (2005) [French], found that morphologically complex pseudo-words (*rapiduit*) prime their roots (*rapide* ‘rapid’), in contrast to form-overlapping non complex pseudo words. This is true whether the pseudo words are interpretable or not.

It is also possible to combine a priming paradigm with ERP. When priming occurs, there is a reduction in ERP amplitude peaking at 400ms, called the N400 effect. Münte et al. (1999) [German] found an N400 reduction when priming regular nouns with their stems. This effect was not observed for irregular nouns, suggesting that regular nouns are decomposed, while irregular ones are not.

Several studies investigating reading of correct affixed and un-affixed individual words using EEG (electroencephalography) and MEG (magnetoencephalography) provide further evidence for decomposition. Affixed words were shown to differ in amplitude from non-affixed ones both in early stages at around 190 ms (Lavric et al., 2012; Zweig and Pykkänen, 2009) as well as later stages around 400 ms (with N400 effect) (Vartiainen et al., 2009; Leinonen et al., 2009). Together, these studies provide a strong case for decomposition of at least some affixed words during reading.

3.2.2 Morphology in Concatenative Languages: Types of Affixation

In concatenative languages, morphological complexity stems primarily from affixation and compounding. Simple words such as *table* are single morphemes, which presumably require no special morphological processing during word recognition. On the other hand, some or all complex words are arguably decomposed during word recognition (e.g. Taft and Forster 1975), thus requiring some sort of morphological step in the processes. Much of the research on reading complex words in these languages focuses on reading different types of affixed words.²

The linguistic classification of affixes as derivational vs. inflectional has been used in studies of word recognition. Inflectional affixes serve a grammatical function (e.g. the plural suffix -‘s’ in the word *cats* in the sentence *There are many cats*. The omission of this type of affix typically doesn’t affect meaning, especially given context, although it does make the sentence ungrammatical (e.g. **There are many cat*). On the other hand, derivational affixes

²While there is also a body of research on compound words, this falls outside of the scope of the dissertation and will therefore not be discussed here.

contribute directly to the semantic meaning of the word or else change the grammatical category of a word (e.g. the prefix ‘im’- in the word *impossible*, where the meaning of the word is reversed by addition of the affix ‘im’-. In addition to their function, derivational and inflectional affixes differ in other respects as well. Many inflectional affixes are less productive than derivational ones. For example, the plural ‘-s’ affix in English applies to all count nouns and is prevalent in speech. There is no English derivational affix comparable in productivity.

Results from a body of studies suggest that decomposition only occurs for words with inflectional affixes and not derivational ones (see Section 3.3.3 for models). Thus, given this approach, the inflectionally affixed word *cats* is not read holistically, but rather broken up into its components *cat* and *s*. In contrast the derivationally affixed word *preview* is not broken into *pre* and *view* and is read holistically. Alternatively, a case can be made that the actual factor determining whether whole words or morphemes are accessed is frequency or productivity. For instance, there are studies that suggest that higher surface frequency words have both whole stem and morpheme representations, while lower surface frequency ones have only morpheme representations and have obligatory decomposition (e.g. Meunier and Segui 1999). Relative stem to surface frequency may also play a role here (e.g. Taft 2004).

Evidence from ERP and MEG studies suggests that while words with both inflectional and derivational affixes are decomposed, the cost of this decomposition is greater at different stages of reading. Studies comparing reading derivational words with monomorphemic ones found differences in amplitude around 190ms after stimulus presentation (Lavric et al. 2012, Zweig and Pykkänen 2009). Those comparing inflectional words with monomorphemic ones observed differences around 400 ms (N400 effect) following presentation (Vartiainen et al. 2009, Leinonen et al. 2009). These different time frames suggest that costs for processing derivational complexity occurs earlier, while inflectional occurs later. For further discussion, see Chapter 7.

3.2.3 Morphology in Templatic Languages

There have been few studies addressing the role of morphology in reading affixed words in templatic languages. Rather, the focus has been on the role of morphology in reading the typical Semitic word consisting of a root and a template.

Frost et al. (1997) and Deutsch et al. (1998) have investigated morphological priming in Hebrew as a Semitic templatic language. Analogous to the studies in concatenative languages looking at affix and stem priming, these studies examined root and pattern priming. With nouns, Frost et al. (1997) found that words sharing a template alone did not prime one another (e.g. *Ta**R**G**i**L* ‘exercise’ did not prime *Ta**K**L**i**T* ‘record’). Words sharing a root (e.g. *Za**M**a**R*** ‘singer’ and *Ti**Z**M**o**R**e**T* ‘orchestra’ did prime one another. Moreover, this priming appears to be purely morphological in nature as two words that are semantically, but not morphologically related do not prime (e.g. *Ti**Z**M**o**R**e**T* ‘orchestra’ and *Na**G**a**N*** ‘instrument player’). In a follow up study with verbs, Deutsch et al. (1998), observed that priming occurs when words share either a root or template. The difference in template priming between verbs and nouns is not surprising. As discussed in Chapter 2, there is a limited closed class of verb templates (7 in Hebrew) and a far more extensive set of noun templates. Furthermore, verb templates contribute more directly to a word structure than noun templates do, indicating aspects such as passiveness and reflexivity of the verb. In contrast, while certain noun forms may reflect properties of the noun (similar to the -‘er’ suffix in English used to form agent nouns), many do not provide any information.

Further evidence of morphology playing a role in reading templatic words comes from letter transposition studies. In contrast to concatenative languages, where words with transposed letters prime, nouns with transposed root letters do not prime (see Frost 2012 for a review). Transposition effects are discussed in more detail in Chapter 4. At the very least, this suggests that templatic nouns are not processed as whole units (i.e. they are decomposed into a root and template), while concatenative nouns are.

Overall, these studies suggest that in templatic languages, morphological processing and

possibly decomposition into a root and template occur during reading just as stem and affix processing occurs in concatenative languages. These processes may be completely different in mechanism and timing, and part of the goal of this dissertation is to better understand the role morphology plays in reading templatic words.

3.3 Models of Visual Word Recognition and Orthographic Encoding

This section introduces some of the key models of word recognition. The models in this section are general models, while models looking at complex words specifically are discussed in the next section. The goal of these models is to provide a universal mechanism, which should be applicable to any language including templatic ones.

3.3.1 Model Considerations

In the past few decades a significant amount of research has been done on reading and the mechanisms involved in reading. In this section, I discuss some of the general considerations and findings that are relevant to model selection. At this stage, models remain somewhat fluid in order to adjust to new findings; many early models have been restructured to account for new studies. It is important to keep this fluidity in mind when reviewing the studies presented in this section.

Letter Position Flexibility

In early reading models letter position is precisely encoded (e.g. Coltheart et al. 1993, McClelland and Rumelhart 1981, Whitney et al. 1996). That is, each letter is encoded according to its position relative to the beginning of the word, where there is one encoding for a letter X Position 1 and a different encoding for letter X Position 2. Thus, the word STRING would trigger S Position 1, T Position 2, R Position 3 and I Position 4, N Position 5 and G Position 6. Such models predict that the word STRING may activate a word like STRONG, which matches in all but one letter and less so a sequence SRTING where two letters do not match.

A series of studies looking at masked priming with transposed letters (TL) provide evidence against a strict letter encoding approach. In a masked priming paradigm a prime is presented very quickly (40ms) and masked by some non-letter sequence (e.g. #####). Using this paradigm a prime is not consciously perceived; however the subject is able to access the prime and an identity prime successfully primes its target as with non-masked priming (e.g. *judge* priming *judge*). The TL studies showed that a word with transposed letters can also prime its target (*jugde* priming *judge*) (e.g. Duñabeitia et al. 2007). These results suggest that the sequence SRTING does in fact activate the word STRING, suggesting that letter position is at least somewhat flexible. Further details of letter transposition studies are discussed in Chapter 4. The key finding here is that priming with transposed letters is strong evidence against a strict position-dependent orthographic reading model.

Orthography and Morphology vs Semantics in Reading

Word recognition requires multiple components including (a) letter recognition, (b) word identification, (c) understanding the word and, if applicable, (d) integrating it into a sentence or utterance. A body of research is focused on the mechanisms involving the word recognition or identification stage, which is also the focus of this dissertation. One of the important aspects of understanding recognition has been investigating whether or not semantics plays a role. A common approach to determining semantic involvement has been to compare reading complex affixed words (e.g. *preacher*) with words that are pseudo-morphological (e.g. *corner*) or to novel morphological pseudo-words (e.g. *spendation*). In this way it is possible to assess whether morphology and semantics are intertwined in recognition or if morphological processing operates on orthographic principles alone. If complex pseudo-words and pseudo-complex words are initially treated like complex real words, it suggests that semantics is not important at early stages and that readers rely on orthography instead.

A number of studies have shown that priming only occurs when there is a semantically transparent relationship between primes and targets; this result suggests that semantic processing is part of word recognition (e.g. Meunier and Longtin 2007; Marslen-Wilson and

Warren 1994). However, these studies were performed with consciously perceived visual or cross-modal primes. The challenge with this line of inquiry is that semantic integration (in a sentence context) occurs fairly quickly. Evidence from ERP shows that readers integrate the semantic meaning of a word into a sentence by 400 ms after word presentation. This is evident from the N400 effect, which manifests as a difference in amplitude of a positive wave form that peaks around 400 ms. The N400 peak following a word in a sentence that is semantically anomalous (e.g. following the word *cat*, in *Jerry baked a delicious **cat** yesterday*), has greater amplitude than a non anomalous word in an analogous sentence (e.g. *cake* in *Sam baked a cake yesterday* (Kutas et al. 1980)).

In order to investigate early word recognition, it is necessary to access an earlier time frame. This has been done using behavioral measure such as masked priming and electrophysiological measures of ERP and MEG (described below). In masked priming, presentation time is controlled to be short (40 ms) and not consciously perceived (see Section 3.3.1), but does not allow for continuous response measurements with lexical decisions measured after target presentation. ERP and MEG provide more continuous response measures, while some presentation methods do not control stimulus presentation. Some studies combine both of these methods. In masked priming studies, pseudo-morphological and novel morphological words have been shown to prime (e.g. Lavric et al. 2007; Longtin and Meunier 2005; Rastle et al. 2004; Longtin et al. 2003; Rastle and Davis 2003). In contrast to studies with overt visual primes, these results suggest that in early stages of word recognition, semantics do not play a role (see Rastle and Davis 2008 for a review).

Nevertheless, even when using time-sensitive measures, there is some discrepancy as to the role of semantics in word recognition. In an MEG study measuring brain responses while reading individual words in a lexical decision task, Zweig and Pylkkänen (2009) found that pseudo-derived words patterned with monomorphemic words. Using an identical task with ERP measurements, Lavric et al. (2012) observed pseudo-complex words patterning with complex words instead. These continued discrepancies suggest that further investigation must be done to parse out the role of semantics in early word recognition.

Lexicalist vs. Distributed

Reading models can be either lexicalist or distributed. Lexicalist reading models operate under the principle that words are stored in a lexicon where words or morphemes are typically represented by their own nodes in the model. In distributed models, there is no lexicon consisting of words or morphemes. Instead, readers rely on features and/or probabilities for word retrieval. In this section, I briefly review both types of models. However, given that most research to date has been done in the lexicalist framework (e.g. the experiments described in Section 3.2) and no compelling evidence has come forth against it, the rest of the dissertation will primarily take into account lexicalist models.

3.3.2 Lexicalist Reading Models

In this subsection, I describe some of the lexicalist models of reading. These models all share the property of assuming some sort of lexicon in the brain which is accessed during reading. The models in this section are based primarily on processing of single mono-morphemic words. Models accounting for reading of affixed words is described in Section 3.3.3.

Sequential Encoding Regulated by Inputs to Oscillations within Letter units Framework(SERIOR)

SERIOR is a framework developed by Whitney and Cornelissen (2008a), Whitney and Lavidor (2004), and Whitney (2001); the goal of SERIOR is to be neurobiologically plausible in addition to accounting for empirical data on reading. The model consists of five layers: (1) a retinal layer, (2) a featural layer, (3) a letter level, (4) a bigram level, and a (5) word level. During reading letters are scanned from left to right (or right to left in languages read in that direction) and words are identified serially as the input is processed at the different levels.

Both the retinal and featural levels are retinotopic. The nodes at the retinal layer represent actual pixels, which are subsequently translated into sub-orthographic units at the featural level. The retinal information is also used to get letter location information. Activa-

tion level is highest at fixation, decreasing as distance from fixation increases, resulting in an upside down v-shaped activation slope. Hemisphere information is then used to convert the activation slope to be greatest at the first letter and decrease subsequently. Right hemisphere features have strong excitation with greatest excitation at the edge of the right hemisphere. Left hemisphere features essentially maintain excitation since the slope is already in the right direction. As a result the activation slope is now decreasing from left to right. The SERIOL model does account for right to left languages as well, where the same processes occur, but are reversed by hemisphere.

At the letter level, letters are identified and carry relative location information expressed through relative activation level as described above. The activation information is then used to identify bigrams. Bigrams consist of an ordered two letters or a letter and an edge pair and need not be adjacent (e.g. for *WORD* bigrams include *W WO WR WD OR OD RD and D*). These open bigrams are activated if two letters fire within 50 ms of each other. Adjacent bigrams are more active than distant ones. These weighted bigrams then activate a word.

The SERIOL model can account for flexible position effects observed with priming words due to the feature and bigram layers (Whitney and Cornelissen 2008b, Whitney 2001). The SERIOL model also accounts for letter position effects. Studies show that first and last letters are best perceived (Bouma 1973, Legge et al. 2001), which is in line with a fixation point at the center and serial processing and graded activation as modeled with SERIOL.

SERIALIZATION OF LETTERS (SERIOL2)

The SERIOL2 model is an extension of the SERIOL model developed by Whitney and Marton (2013). The goal of this extension is to account for languages that read from right to left in addition to the left to right. SERIOL2 primarily differs from SERIOL at the retinotopic retinal and featural levels. This extension was developed based on evidence from comparing reading in Hebrew and English.

Readers are briefly presented with trigrams which are subsequently masked, after which they are asked to identify the letters in the trigram. Letters are positioned relative to a

fixation point such that they can appear in positions R-4 to R4 where a negative number indicates position to the left of the fixation point and a positive to the right. For English readers, accuracy was at ceiling in the left visual field, but in the right visual field it decreased with distance to fixation as predicted by the SERIOL model. However, for Hebrew readers, this effect was not reversed as expected. Instead, there was a strong positional effect at R-3 and R-2 in the left hemisphere as well as at R3 in the right. Furthermore, initial letters that are positioned at fixation R0 are harder to recognize.

In order to account for the Hebrew data, the SERIOL2 model added serial firing of the activation units based on retinal information. This is in contrast to the original model in which visual field information played a stronger role in determining positional information. It is important to note that while this model does take into account the direction of reading in Hebrew, it does not account for any morphological differences between concatenative and templatic languages.

Self-Organizing Lexical Acquisition and Recognition (SOLAR)

A competing model of orthographic processing is the Self-Organizing Lexical Acquisition and Recognition (SOLAR) model developed by Davis (2001). The SOLAR model centers on activation gradients which relate to letter position. Words are serially scanned letter by letter from left to right (for languages read in that direction) with order assigned based on relative position to one another. While the activation occurs serially, this is very rapid so that actual recognition occurs in parallel. It is also self-organizing.

Each letter read in from the beginning to the end of a word has an activation letter which decreases by increments of 1. In the word STRING, S has activation of 6, T-5, R-4, I-3, N-2, and G-1. Thus the string SRTING (S-6,R-5,T-4,I-3,N-2,G-1) would differ from STRING only by 2 positional differences total (-1 for R and -1 for T) and no letter differences. The input is matched up with potential words based on degree of activation overlap.

The model takes a parameter sigma representing the uncertainty of letter position. The value of sigma determines the required degree of overlap for a match to occur. It is possible to set this value high enough to allow reading of words with transposed letters, accounting

for masked priming with transposed letters.

Interactive Activation Model

Another model of reading is the Interactive Activation Model or IAM developed by Rumelhart and McClelland (1982) and McClelland and Rumelhart (1981) is composed of several layers: a feature level, a letter level, and a word level and a higher level. It operates under the principle that word recognition occurs with the help of top down processes in addition to the commonly assumed bottom-up ones. That is in addition to using features to recognize letters and then letters to recognize words and so on, context can help with word recognition and word recognition can help with letter recognition. As with other connectionist models, all of the interactions or steps in the model occur through excitation and inhibition of nodes representing neural units.

Top-down effects in word recognition have been observed in studies since the 1960s in the seminal study by Reicher (1969). This study compared individual letter recognition with letter recognition in words in pronounceable non-words and in non-pronounceable letter sequences. Using a patterned mask and a Tachistoscope to control presentation time, he measured accuracy of letter detection. Subjects performed significantly better at recognizing letters in words than in the non-words or individually, which supports the theory that knowledge of a target word itself aids in the recognition of its letters.

Further studies using the masked pattern paradigm showed that there is an advantage for letter recognition in pronounceable non-words such as *slumf* over non-pronounceable ones (Aderman and Smith, 1971). Furthermore low neighborhood density at the critical letter (e.g. *_ync* with only one possible letters S vs. *_art* with many more) did not give any advantage for success of recognition under this pattern masking paradigm (Johnston, 1978). IAM strives to account for all of these findings.

In the IAM model, letters are perceived in parallel, rather than sequentially as in the SERIOL/SOLAR models. Within some limit of visual field, letters are seen at the same time. Similarly, access to the different levels of word recognition occurs simultaneously. In this way, letters are being recognized at the same time as potential words are being matched

to the input and so on. This allows for top-down and bottom-up processes to occur at the same time.

Spatial Coding Model

Davis (2010b) developed a subsequent model called the Spatial Coding Model which incorporates methods from the SOLAR and IA models. On the front end, the model is similar to the SOLAR model, however it does not self-organize. Its back end is similar to the IA model, with letter feature, letter, and word levels. Position information and matching computations are performed in line with the SOLAR model. This new model was developed primarily to be able to account for the empirical information using the SOLAR model, while using a more simple network mechanism as laid out by the IA model.

Bi-Modal Interactive Activation Model

Finally, the Bi-Modal Interactive Activation Model (BIAM), developed by Grainger and Holcomb (2009), Grainger et al. (2005), Jacobs et al. (1998), and Grainger and Ferrand (1994), is another model based on the IAM model. The goal of this model is to account for both reading and pronunciation of words and nonwords. A key feature of this model is its dual phonological and orthographic routes, whereby words activate both sound and letter units. Both routes are accessed in parallel to identify a word during reading. This type of model is motivated by the fact that words are presented either as auditory or orthographic input and that both of these can activate the same meaning. In addition, it accounts for the pronunciation of a word when reading it aloud. Orthographic processing is more coarse grained and attuned to general form information for quick recognition. By contrast, phonological processing is more fine-grained and slow as letter combinations are matched with phonemes. Letter position coding is relative to other letters in the word rather than occupying a particular position in space. In the coarse-grained orthographic processing both adjacent and non-adjacent bigrams are activated, accounting for transposed letter effects.

Distributed Reading Models

Distributed models operate on the basis of features and connections in a connectionist framework. These are meant to represent neurons or groups of neurons. I briefly give an account of a Parallel Distributed Processing model as laid out in Plaut (1997). In this model, different properties of a word such as orthography, phonology and semantic meaning are distributed across units. Activation patterns across these units form words. Such a model directly accounts for effects such as frequency by the strength of activation of particular connections and patterns. These models are designed to account not only for reading, but also for pronunciation of read words. For instance, patterns from similar words are activated when reading a novel word, providing a mechanism for pronouncing it. Other such distributed models include Seidenberg and McClelland (1989) and Plaut et al. (1996).

3.3.3 Models of Reading Complex Words

In this section I briefly introduce reading models of affixed words. These can be divided into three types based on the level of decomposition of affixed words that they predict. In a Full Listing Model, all affixed words are read holistically and no decomposition occurs. In a Full Decomposition Model, all affixed words are decomposed. Finally, in a Dual Route Model, some affixed words are decomposed, while others are not, depending on factors such as frequency.

Based on empirical evidence, many models which do involve decomposition (e.g. Baayen and Schreuder 1995) concur that reading complex words consists of several stages. Namely, affixed words must be (1) broken into their stems and affixes, (2) recombined, and (3) interpreted both grammatically and semantically. Models involving decomposition then incorporate these stages.

Full Listing Models

Full Listing models have only one route for word recognition for affixed words, in which they are always processed holistically. I only briefly describe evidence for full listing models as these are essentially outdated. Since the full listing hypothesis was proposed, a large body of studies have shown evidence for at least some affixed words being decomposed (see Section 3.2). Given the strength of this evidence, a Full Listing hypothesis is highly unlikely. I briefly describe some of the theoretical considerations and evidence that was used in support of a Full Listing account in order to provide some background of these models.

In lieu of briefly mentioning all studies providing evidence in favor of a Full Listing approach, I discuss the one such study to illustrate how results from Full Listing studies can be interpreted in favor of a theory involving decomposition. One seminal study conducted by Manelis and Tharp (1977) consisted of two experiments, the results of which are used in support of a Full Listing account. The first experiment is a lexical decision task, in which reaction times are compared for affixed words and pseudo-affixed words (e.g. *teacher* and *sister*), where longer RTs (reaction times) would be evidence of decomposition. They found that RTs did not differ between the two types of words, suggesting that decomposition did not occur. However, the comparison in this study is problematic. Results of later studies such as Lavric et al. (2012) (as discussed in Section 3.3.1) suggest that pseudo-affixed words are also decomposed in the initial stage of word recognition. Thus, these results can be interpreted in line with a decomposition model. In a second experiment, subjects were presented with words consisting of a stem and an affix (e.g. *Snowed*) and pseudo-words consisting of an illegal stem and affix combination (e.g. *Snowen*). Following the word or pseudo-word, subjects were presented with a picture and asked to determine whether it matched with the meaning of the stem or not. Subjects had longer RT for pseudo-words than words, which the authors interpreted to be evidence against decomposition of the words. Again, this result can be interpreted in line with a decomposition account. Since the task involves a semantic component (picture identification), it is not surprising that a word would

have shorter reaction times than a pseudo-word. Just as with experiment 1, decomposition may be occurring for both words and affixed pseudo-words contributing to the same initial lag. However, since pseudo-words also lack semantic meaning, they have an additional load at the recombination step. In summary, the results of the Manelis and Tharp (1977) study do not provide clear evidence in support of a full listing model.

The theoretical framework for the Full Listing approach in particular has been laid out by Butterworth (1983) where all words read are read holistically and go through a single route. Presumably, the Full Listing approach is also in line with affixed words being treated like any other words in the models described in Sections 3.3.2 and 3.3.2. In this sense, a Full Listing approach is compatible with many models and need to be associated with one in particular so long as the model does not have a separate component for affixed words.

Full Decomposition Models

Full Decomposition Models propose one route for all affixed words to undergo decomposition. I introduce two iterations of these models here. The first of these models was proposed by Marcus Taft and is layed out in Taft and Forster (1975), Taft (1988) and further developed in Taft (2004). This is a seminal model for the Full Decomposition approach. The other model described here is a more recent model iteration of the model laid out by Crepaldi et al. (2010).

The key component to Taft's model (Taft, 2003, 2004) is that words are accessed by the stem. This is true whether the stem is bound or free. Evidence for stem-based retrieval comes from the base frequency effect, where words with same surface (whole word) frequency, but greater stem frequency are read more quickly (e.g. Taft 1979). Another key component to Taft's model's is the role of syllable structure in decomposition and word recognition in general. That is all polysyllabic words are broken into their syllables. This is developed further in Taft (2003). Words are read into the form code level where they are broken up into morphemes and polysyllabic units. The next level is a lemma level in which information is available for words whose meaning is not transparent from constituent morphemes (e.g.

the word *feathery*, meaning ‘light’ rather than ‘similar to feathers’). Finally the lemma, semantic and syntactic information, is combined. In this model, base frequency effects occur early on during decomposition, whereas surface frequency effects emerge later at the stage of recombination. At this stage, the frequency predicts the ease with which the full form is retrieved.

In the model proposed by Crepaldi et al. (2010) is very similar to the one proposed by Taft (2004). A word first goes through morpho-orthographic segmentation, followed by an orthographic level, a lemma level and then a semantic level. The models differ in that Crepaldi et al. (2010) does not posit a recombination stage. Rather surface level frequency effects can be explained by neighboring word competition where words such as rare plurals face more frequent neighborhood competitors with higher frequency.

Dual Route Model

In contrast to both Full Listing and Fill Decomposition Models, dual route models have two different routes for lexical retrieval.³ One route is used for processing words as a whole and the other for decomposing them. Thus, a complex word such as *tried* activates nodes for *try*, *ed* and *tried*. These processes typically occur in parallel. In this section, I briefly introduce a few of these models.

The Augmented Addressed Morphology Model

The Augmented Addressed Morphology Model (AAM) proposed by Caramazza et al. (1988) and Caramazza et al. (1985) accounts for both real words and pseudo-words or novel words. Words activate both whole word and morphological representations, while novel words only activate morphological representations. Activation of word and morpheme units occurs simultaneously. A word will be retrieved whenever one of these routes reaches a threshold activation. The assumption under this model is that known words will more

³It is important to note here, that Dual Route Models can refer to two types of models. The ones discussed here have two routes in terms of decomposition. The other type of Dual Route Model is one in which orthographic (lexical) and phonological (non-lexical) information is accessed in parallel (e.g. Coltheart et al. 1993, Paap and Noel 1991, etc.). These two types of models are not directly related to one another.

quickly be retrieved through the whole word representation as this route is faster than the decomposition one. Under this initial iteration the words are primarily accessed through whole word representations. In later iterations of this model (Chialant et al. 1995), words in which morphemes are more frequent in relation to surface representations are activated by the decomposition route.

Parallel Dual Route Model

The Parallel Dual Route Model laid out in Baayen et al. (1997) and Schreuder and BAAYEN (1995), like the AAM model has two routes for word recognition. In the whole word route, words are mapped onto a lemma layer with features which is then processed in a semantic and syntactic layer. At the same time, in the decomposition route, words are decomposed and each of the morphemes map onto the lemma layer. Following that is a silencing layer in which features are matched. Finally, there is top down feedback from a semantic and syntactic layer. The key component of this model is that these processes occur simultaneously and in parallel.

3.4 Time Course of Visual Word Recognition

Vital to the complete understanding of word recognition is understanding the time-course of each of its steps. Initially, this could only be studied indirectly by looking separately at tasks that are considered lower level processes, such as recognition, and higher level processes, such as semantic integration. Tools such as positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) provided good spatial resolution, but poor temporal resolution. Paradigms such as masked priming, controlling duration of word presentation provided insight into early processing, but not to the different steps of the process. With advances in time sensitive brain scanning techniques of EEG and MEG and discovery of ERP and MEG components, the task of mapping out this time-course has been able to move forward. In this section I give a brief outline a timeline of visual word recognition based on this research.

3.4.1 *Word Recognition and Early Effects*

Word recognition occurs fairly quickly after word presentation. The possibility of masked priming serves as evidence for word recognition occurring within 40 ms of seeing a word (e.g. Duñabeitia et al. 2007). In these experiments, words are presented for as little as 40 ms and yet they are able to prime targets with shared form and morphological units. It is possible that actual recognition takes somewhat longer, however at least letter recognition is possible within a 40 ms window.

Results of ERP studies show evidence of recognition around 100 ms after stimulus presentation (e.g. Sereno et al. 1998, Dufau et al. 2008). Sereno et al. (1998) found lexicality effects (words vs pseudo words and consonant strings) at the P1 around 100 ms, frequency effects (high versus low) at the N1 within 132 ms and regularity effects (regular versus irregular) at the P2 within 200 ms after stimulus presentation. Combining priming and ERP, Dufau et al. (2008) found that starting around 100 ms after stimulus presentation readers are sensitive to location changes of identity primes.

3.4.2 *Semantic Integration*

Semantic integration occurs within 400 ms of seeing a word as evidenced by ERP studies. The negative going peak which is observed around this time has been shown to be sensitive to semantic manipulations. In a sentential context, a word that is semantically anomalous (e.g. the word *cat* in the sentence ‘The man baked the *cat*’) has a greater amplitude N400 peak than an analogous word that is semantically coherent (e.g. the word *cake* in the sentence ‘The man baked the *cake*’) as discussed in Section 3.3.1 (Kutas et al. 1980). The N400 effect has also been widely observed when reading individual words that are primed by identical or semantically related words (e.g. McCarthy and Nobre 1993). Together these results point to a semantic processing stage of word recognition occurring around 400ms after word presentation.

Frequency effects are also observed at the 400 ms time (e.g. Dambacher et al. 2006,

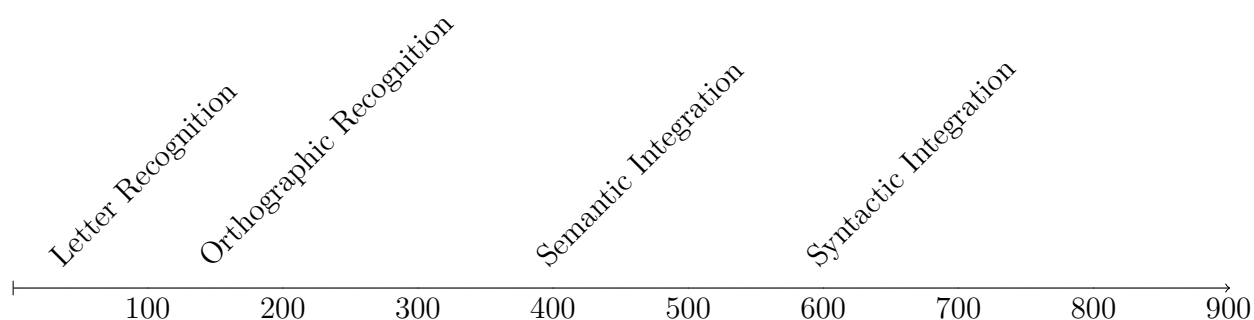
Barber et al. 2004). More frequent words have lower amplitude N400s and frequency effects modulate predictability effects in this time frame. It is important to note that syllable frequency effects are found at an earlier time window, beginning around 150 ms (Barber et al. 2004). Thus, frequency plays a role both in early and later stages of reading.

3.4.3 Syntactic Integration

While the focus of this dissertation is primarily individual word recognition, it is important to note that later effects related to sentence processing have also been observed. The P600 effect, peaking around 600 ms post stimulus presentation is sensitive to grammatical anomalies. For instance, in a seminal paper, Osterhout and Holcomb (1992) showed that a larger amplitude positive peak at 600 ms is observed for sentences in which a word is grammatically anomalous (e.g. the word *to* in the sentence ‘The man convinced *to* buy her flowers’, where convinced is missing its second argument) as compared to a word in an equivalent grammatically coherent sentence (e.g. the word *her* in ‘The man convinced *her* to buy flowers’). This later time period is linked to grammatical processing and integration.

3.4.4 A Timeline

Evidence from current research points to letter recognition occur fairly early on within 40 ms. This is followed by position coding and orthographic (non-semantic) recognition at around 100 ms. At this stage frequency is important, likely for the recognition itself. By about 400 ms the semantic information is processed. Finally, at around 600 ms any grammatical information (at the sentence level) is integrated. This approximated time course will be a point of reference for the rest of the dissertation.



3.5 Auditory Word Recognition: General Considerations

Spoken word recognition is inherently different from visual word recognition. Some of these differences are not specific to language and need not be described in detail here. For instance, auditory recognition engages the auditory system and not the visual one and the signals themselves are acoustic and not visual/orthographic. There are also less apparent processes and considerations specific to word recognition. It is important to introduce these before considering the role of morphology in word recognition or looking at any specific models. This section covers some of these key considerations.

Coarticulation

One key consideration for auditory word recognition is that in natural speech, the pronunciation of a sound affects the pronunciation of its neighbors (see e.g. Farnetani and Recasens 1993, Recasens 1991, and Fowler and Saltzman 1993). This is a result of articulation assimilation such that when a sound is being articulated, the articulation of the following sound retains some of the properties of the preceding one (e.g. the nasal passageway may remain open from producing a nasal so that the following vowel is articulated nasally). Similarly, in anticipation of the production of a sound, the mouth begins moving in the direction of the following sound while the current sound is being produced. Thus sounds assimilate to preceding and/or following sounds, becoming more similar to one another; this phenomenon

is termed coarticulation.⁴

As described above, from an articulatory perspective coarticulation manifests in a sound taking on articulation of a nearby sound (e.g. an oral vowel preceding a nasal being produced in a nasal manner). In terms of the signal itself (i.e. the sound produced) this translates into changes in the acoustic properties such as the formants and duration. For instance, Farnetani and Recasens (1993) showed that the duration of vowels [a] and [i] in Italian varied depending on preceding consonant (e.g. shorter duration before [ʃ] than [t]).

For word recognition, the important finding is that listeners are sensitive to coarticulation effects and use them as cues for phoneme (and subsequently word) recognition (e.g. Raphael 1972). Thus sounds are not perceived individually; rather the properties of one sound may relay information about another. This has implications for perception in noisy environments where listeners may rely on coarticulation cues to restore sounds that are masked by noise (for further discussion, see Chapter 6).

3.5.1 Uniqueness Point

One key consideration for auditory word recognition is that auditory stimuli, unlike visual ones, are not presented all at once, but rather are perceived incrementally through time. Thus, a listener is initially only presented with part of the information needed to recognize a word, with more and more of the signal available with time. Importantly, a person does not necessarily need to hear an entire word before being able to recognize it to the exclusion of all others. There is a point in each word where there are no other words that share the same phonetic sequence. For a word like *star* this point does not come until the last sound is heard. However, for some words this point comes earlier on (e.g. for the word *strength*

⁴While the focus of this dissertation and the discussion here is on single word recognition, it is important to note that coarticulation effects are not restricted by word-boundaries. That is, since in natural speech there are no pauses between words, coarticulation effects can occur between adjacent sounds in neighboring words as well. Furthermore, coarticulation need not be limited to adjacent sounds. For instance, Daniloff and Moll (1968) investigated the rounding assimilation in the production of sentences in which a number of consecutive consonants in a phrase preceded a [u] (e.g. in the phrase *less true* [les tru]). They found that speakers began rounding in preparation for the [u] at the closure of the first consonant in the sequence, up to four consonants before the [u] sound.

[st.ɪɛŋθ], there are no phonetic neighbors sharing [st.ɪɛŋ]). It has been shown that listeners are in fact able to recognize a word around this point at which it differs from neighboring words (Grosjean 1980). This point at which recognition happens is called a uniqueness point (UP).⁵

Gating Experiments

The ability of listeners to recognize words at their uniqueness points has been shown through a variety of methods, the most common of which is the gating method (see e.g. Grosjean 1980, Tyler 1984). In this technique, a person is presented with longer and longer segments of a word beginning at word onset. These segments, called gates, are presented one at a time until the final segment is the word in its entirety. Length of segments has varied across experiments, but is typically incremented at durations 40 ms, such that the first segment is 40 ms, the second is 80 and so on (e.g. Grosjean 1980 had 30 ms segments and Tyler 1984 had 50 ms ones). While this may vary with rate of speech and length of word, a gate is typically shorter than the duration of a phone. For instance, Grosjean (1980) reported having 11 increments for the word *smoke*, which was 330 ms in length, spoken at ‘normal speech rate’ with increments increasing by 30 ms for each gate. After each gate presentation, the listener is asked to identify the word they heard. The perceptual uniqueness point is the point at which listeners identify a given word correctly and no other. The results of these experiments showed that listeners recognition correlated with the point at which a word diverged from neighbors with the same initial sounds.

Another method that has been used for investigating perception of uniqueness points is comparing reaction times for recognition of words with varying points of divergence. In French, Radeau et al. (1989) found that listeners were quicker to decide on the gender of a word with an earlier uniqueness point than a later one. In a follow-up study using the same paradigm, Radeau et al. (2000) found that the speech rate interacted with the

⁵This discussion is on single word recognition. In context, a uniqueness point may vary in that more information is present than just the speech sounds of the given word. Rather, further words may be excluded on the basis of context alone. See further discussion of the role of context in descriptions of reading models in Section 3.7

interaction between point of divergence and recognition. In individual word recognition (without context), uniqueness point only played a role at medium or slow speech rate (3.6 and 2.2 syllables per second respectively) and not at a faster speech rate (5.6 syllables per second). Given that words were presented individually, the findings of this study do not directly transfer to natural speech, however. That is, typically when words are spoken at a normal speech rate, they are spoken in context.

Since the uniqueness point is correlated with the point at which words diverge from one another, it is possible to investigate UP to some extent purely computationally. That is, given a database of phonetically transcribed words, it is possible to roughly predict their uniqueness points. Using such a method, Luce (1986) found that for English words, the point of divergence for shorter words is often at the last last sound. Most words fewer than five phones in length do not have uniqueness points before the final phone.

The studies described until now looked at uniqueness points for morphologically simple (un-affixed) words. Winther Balling and Harald Baayen (2008) and Balling and Baayen (2012) investigated uniqueness points of complex words in Danish. They found evidence of two types of uniqueness points: the one for un-affixed words discussed here (UP1) and the complex uniqueness point (CUP). The latter is the point at which words become distinct from their affixed counterparts (e.g. *read* vs. *reading* vs *reader* etc.) They found that in addition to UP effects for simple words, there were also effects for CUPs. Affixed words with later CUPs took longer to recognize than those with earlier ones.

While uniqueness points have been well studied in concatenative languages, UPs remain understudied in templatic ones. Thus far, there have been no studies of UP in Hebrew and limited ones in Arabic. Templatic words with their inherently complex stems (i.e. consisting of roots and tempates) may have some additional complexity to their uniqueness points. Given the findings regarding CUPs in affixed words in Danish, there may be a version of CUPs for templatic complexity in templatic languages. This type on interaction between templatic complexity and uniqueness points has not yet been studied.

3.6 *Role of Morphology in Auditory Word Recognition*

The role of morphology in word recognition in the auditory domain has been investigated somewhat, albeit less so than in visual word recognition. In this section, I describe some of these key discoveries. The evidence thus far points to parallels in the processing of complex words in these two modalities. Some of the studies have shown differences however and further research is necessary in the auditory domain to better word recognition in the spoken modality.

3.6.1 *Concatenative Languages: Recognizing Complex Words*

A number of behavioral and neurophysiological studies have shown evidence for morphological decomposition of concatenative words into their stems and affixes, just as with visual word recognition. In a lexical decision task, Taft et al. (1986) found that auditory (and visual) lexical decision times increased for subjects identifying non-words which contained prefixes (e.g. *restrile*) than those that did not. This effect was greater when the stems were real stems (e.g. *dejoice*) than when the stems were non-word stems. Together, these results point to decomposition into stems and prefixes during auditory word recognition.

As with visual lexical access, priming has been used to investigate recognition of spoken words. In an auditory priming experiment, Emmorey (1989) found that words sharing a stem, but no semantic relationship, prime one another (e.g. *permit* priming *submit*). He did not observe this same effect for words sharing affixes (e.g. *trying* and *writing*), however.

In ERP studies, Leinonen et al. (2009) found an N400 effect with higher amplitudes peaks for inflected than un-inflected words for auditory as well as visual word recognition. In a further study, Leminen et al. (2011) found evidence of morphological decomposition of both inflected and derived words.

The results of these studies suggest that decomposition into roots and affixes occurs with auditory as well as visual word recognition, at least with certain affixes. Further work needs to be done to get a better understanding of these mechanisms.

3.6.2 *Templatic Languages*

There have been few studies investigating the role of morphology in auditory word recognition in templatic languages.

Several morphological priming studies similar to those conducted in the visual domain with Semitic languages have been replicated in the auditory one. Frost et al. (2000) conducted a cross-modal priming experiment in Hebrew, where primes are auditory and targets are orthographic. They found priming effects with words that share the same root, even when the prime and target are semantically unrelated (e.g. *drixut* meaning ‘alterness’ priming *hadraza* meaning ‘guidance’) Raveh and Schiff (2008) found this same type of root priming in Hebrew in an exclusively auditory priming task.

Boudelaa et al. (2010) conducted a mismatch negativity (MMN) ERP study in Arabic comparing mismatches of roots and templates. They found differences in timing of the MMNs between the two morpheme types. As with the priming studies, this suggests that the root and template morphemes play separate roles in auditory word recognition.

While evidence from these studies points to the root and template playing a role in templatic auditory word recognition, further research into this is needed to better understand this role. One of the goals of this dissertation is to further investigate auditory word recognition in Hebrew as a templatic language.

3.7 *Models of Auditory Word Recognition*

In this section, I lay out some of the main models of auditory word recognition. The goals of these models are to model the recognition process based on empirical findings.

3.7.1 *Models*

Logogen Model of Auditory Word Recognition

The logogen model developed by Morton (1964), Morton (1968) and Morton (1969) is a seminal model of word recognition applicable to both auditory and visual modalities. I focus

here on summarizing the model's handling of auditory processing of individual words. In its first iterations, the model consisted of four main components (1) an auditory analysis system, (2) a logogen system, (3) a cognitive system and (4) an output buffer. Input is first processed in the auditory analysis module where it is converted from raw auditory input into code representing the input. This then is sent to the logogen system, which is comprised of individual logogens each responsible for the recognition of an individual word. The logogens have semantic, phonological and acoustic features of their word. The logogen system also receives context and other cognitive information from the cognitive system. When features are matched, logogens become activated. Once activation of a logogen reaches a threshold, a word output is generated. The output then goes through an 'output buffer' layer, which it needs to pass for the word to be recognized, otherwise the output is recycled back. The buffer also compares activation between multiple outputs if more than one logogen is activated such that only one output can be chosen.

A key component of this model is the role of the context system which takes into account transitional probability of a particular word in a given context. During recognition, this increases activation for corresponding logogens. The threshold of recognition interplays with the availability of context where context decreases the threshold for recognition for particular logogens. Conversely, the amount of information present in the word presentation (i.e. signal to noise ratio in the case of auditory information) decreases the need for context information. Threshold of activation is also modulated by word frequency and how recently a logogen was activated (priming).

An updated version of the model is described in Jackson and Morton (1984) and Morton (1979). In the original model, both auditory and visual input fed into the same logogen system. In newer iterations of the model, the auditory and visual logogens are separate from one another. There is also a separate logogen input and output system, where tasks such as picture naming would only involve the output logogen system and not the input logogen system.

Cohort Model

The cohort model developed by Marslen-Wilson and Welsh (1978) and Marslen-Wilson (1980) is an auditory model of word which builds on the logogen model, extending it to account for the way that auditory information is perceived in real time. In particular, the model is formed around the evidence (described in Section 3.5) of auditory information being continuously processed from the onset of the stimuli and revised with time, as more of the input becomes available. In place of logogens the model has cohorts of words, that are grouped together based on their phonetic overlap beginning at the initial sounds and onward. As the first sound in a word is heard, the cohort of words beginning with that sound are activated. Once, the second sound is heard, a more narrow cohort is selected overlapping in the first two sounds. This narrowing of the cohort continues until a uniqueness point is reached and a particular word is recognized (e.g. for the word *stranger* the first cohort available after hearing [st] includes: *string*, *stranger*, *standard* and *strand*; after hearing [stɹ] this narrows to *string*, *stranger* and *strand*; after hearing [stɹeɪ] this reaches a uniqueness point for *stranger*).⁶

The cohort model has an element of flexibility to allow recognizing words even when they are not accurately produced. At the start of the narrowing process, a complete match is not required, allowing for the recognition of mispronounced sounds or sounds masked by noise. Similarly, if at the end of the narrow process one word remains which is not a perfect match, it can still be recognized as the target. Just as in the logogen mode, contextual (syntactic and semantic) information plays a role in recognition. In the cohort mode, this information assists with cohort narrowing, such that words may be excluded from a cohort based on this information alone.

Interactive Activation Model

⁶This description is an oversimplified in that it does not mention co-articulation effects. Due to co-articulation sounds are not perceived individually, rather in hearing a given sound information about the following sound is already available. Sounds then would not actually be heard and eliminated one by one, but in some more fluid manner.

The Interactive Activation Model developed by McCarthy (1981) applies to auditory as well as visual word recognition and is described in further detail in Section 3.3.2. As with reading a key component of the model is that word recognition relies on both top down and bottom up information. Sounds are converted into acoustic features, which in turn activate phonemes and then finally words. At the same time, top down information at the word level is available for word recognition. In the case of auditory masking for example, where a some sound information is missing, the word level feedback helps fill in gaps.

TRACE

Another model of auditory word recognition is the TRACE model developed by Elman and McClelland (1986) and McClelland and Elman (1986). TRACE is a computational model of speech recognition based on the Interactive Activation Model. The model has three levels: a (1) feature, (2) phoneme, and (3) word level. Acoustic properties of speech are recognized at the feature level with separate detectors for different acoustic properties. At the phone level, phones detectors identify phones based on the features. In order to account for co-articulation, phone detectors differ depending on adjacent phones that have been identified. Final word detectors detect individual words based on phonemes. Excitatory activations occurring between levels with features activating phones and phones activating words. Inhibitions occur within levels with competitors inhibiting one another. The model gets its name from the trace, in the form of an activation pattern, that results from auditory input being analyzed through these different levels.

Distributed Model

Finally, the Distributed Model of Speech Perception is a computational connectionist model developed by Gaskell and Marslen-Wilson (1997). In this model, there is just one layer (a hidden layer) which simultaneously processes phonological, morphological, semantic and syntactic features, all of which are distributed over potential candidates. Thus, phonemes, acoustical features and words are not each identified individually as they are in the TRACE model. Instead, all of these features are for potential candidates. As more of a word is

heard, more candidates can be eliminated. Similarly to the other models, this model also has a context layer which provides information for recognition.

The description of models in this section has focused on recognition of un-affixed words. This is because there is less literature focusing on models of complex auditory word recognition in particular. Instead, the current models are proposed to accommodate complex words (see e.g. Taft et al. 1986) or visual recognition models of complex word recognition are proposed to be able to account for auditory recognition in conjunction with the existing auditory models (see e.g. Baayen and Schreuder 1999). There may be further evolution of auditory models to account for complex words as more empirical data emerges. Conversely, if auditory and visual recognition is shown not to differ in this respect, existing (or emerging) visual models may be amended to account for auditory processing. In either case, further amendments to existing models are necessary to account for the role of templatic morphology in word recognition.

3.8 Time Course of Auditory Word Recognition

In contrast to visual word recognition, auditory word recognition cannot be neatly represented on a time-line. This is because auditory recognition times are variable and difficult to measure. First of all, words themselves take time to present, with duration varying by word. Second of all this variation does not only depend on word length (in sounds), but also other factors such as (1) degree of enunciation, (2) number of words being produced together, (3) individual speaker rate, etc. For these reasons and the presence of uniqueness points, techniques such as ERP or MEG cannot be straightforwardly used to assess time-course. With visual stimuli, the event from which the potential can be measured is the presentation of the word. For auditory stimuli, it is less clear where to measure from: the start of the word presentation, the uniqueness point, the end of the word or some other point in presentation? In spite of these challenges, there have been a number of findings regarding the general time-course of auditory word recognition and I review some of the key ones here. The focus of this section is on individual word recognition rather than recognition in context, which is

outside of the scope of this dissertation.

Studies using monitoring, decision and gating tasks found that listeners recognize words before the entirety of the entire word has been presented (i.e. only until the uniqueness point, see Section 3.5.1 for further discussion). Marslen-Wilson (1980) found that listeners were able to identify words they monitored for within 273 ms of beginning of word presentation, while the word length on average was 367 ms. Similarly, the gating experiments conducted by Grosjean (1980), they found that a listener only needed to hear 199 ms of a word before recognizing it, while words averaged 400 ms in length.

In a carefully controlled MEG experiment, MacGregor et al. (2012) found that words can be distinguished from pseudo-words within 50 ms of the uniqueness point presentation. They compared words and pseudo-words with CVC structure ending in stop consonants, where the uniqueness point was always at the onset of the final stop. The amplitude of the waves for words and pseudo-words were shown to differ beginning 50 ms from the presentation of the uniqueness points.

Together, these studies indicate that the time-course of auditory word recognition is tied closely to the uniqueness point of a word. Thus, different words have different recognition times. Furthermore, once the sounds of a word up to the recognition point are presented, listeners are quick to recognize the word.

3.9 Conclusion

In this chapter, I have provided evidence of morphology playing a role in both visual and auditory word recognition. In particular, affixed words in concatenative languages are decomposed during reading. For templatic languages, there is evidence of similar decomposition into roots and templates for templatic words. While some models account for affixational complexity; it is also necessary to account for templatic complexity. I discuss specific implications both from previous research and the current dissertation in Chapter 8.

Chapter 4

NEW FINDINGS IN TRANSPOSED LETTER EFFECTS IN A TEMPLATIC LANGUAGE: VERBS VERSUS NOUNS AND ROOTS VS TEMPLATES

4.1 Chapter goals

The studies in this chapter focus on the early reading stage of word recognition. The study presents two novel experiments extending the previous work on letter flexibility in Semitic languages. In particular, the goal is to investigate letter flexibility and how this interacts with root and template morphemes and with part of speech (verb vs. noun). These questions are explored in two separate studies discussed in this section below.

4.2 Background

Studies investigating early stages of word recognition have shown robust cross-language letter position flexibility effects using the masked priming paradigm. Numerous studies have shown that words with letter transpositions act as lexical primes similar to identity primed words. These studies have concentrated on concatenative languages from the Indo-European group of languages, such as English (Forster et al. 1987), French (Schoonbaert and Grainger 2004), and Spanish (Perea and Lupker 2004), as well as on concatenative languages from other families such as Basque (Duñabeitia et al. 2007). Letter flexibility has also been observed for Japanese kana, a syllabary writing system (Perea and Pérez 2009). These studies have used the masked priming paradigm, where the prime is presented very briefly (~40 ms) and masked from conscious recognition with a masking pattern such as a set of hash marks (#####). This is done to look at the recognition stage of reading. The results of these studies have shown transposed letter (TL) words successfully priming their targets (e.g. *srtng* priming

string), leading to a widely held view that letter position in reading is universally flexible. This transposition effect has worked best when transposing two adjacent morpheme internal consonant letters.

In related research on several of these languages, orthographic form priming effects have been observed with unrelated words that share letters (e.g. *arts* priming *acts* Perea and Rosa 2000 [Spanish], Ferrand and Grainger 1994 [French], Forster and Taft 1994 [English]). These orthographic effects are separate from any phonological effects (Ferrand and Grainger 1994). Together with the TL priming effects these serve as evidence that reading (of simple un-affixed stems) at the word recognition stage is letter position flexible and morphology independent.

However, evidence from Hebrew and Arabic, with their templatic morphological system, has revealed that letter position flexibility is not universal (e.g. Velan and Frost 2011). In both Hebrew and Arabic, nouns with transposed root letters have been shown to not prime (Velan and Frost 2009 [Hebrew] and Perea et al. 2010 [Arabic]). This evidence poses a challenge for models that allow for across the board letter flexibility (e.g. Davis 2010a). In order to develop a truly universal model, it is then necessary to better understand the role of letter position flexibility in templatic languages.

Studies on Semitic languages indicate that morphology and especially the root morphemes are important to reading. Transposition effects (inflexibility) in Hebrew only apply to the native templatic words that are root-based (Velan and Frost 2011). A minority of borrowed words in Hebrew have a concatenative morphology and exhibit letter position flexibility similar to English and the other concatenative languages (Velan and Frost 2011). Furthermore, a study by Frost et al. (2005) showed that in Hebrew and Arabic, masked priming is not reliably achieved through native Semitic words that share similar orthography (form-based priming), but whose roots were unrelated; e.g. RIPUD (root RPD, upholstery) priming RIKUD (root RKD, dance). Priming was achieved however with orthographically dissimilar but morphologically related words sharing the same root (but otherwise very different); e.g. HaRKaDaH (lead to dance) priming RIKUD (dance) (Deutsch et al. 1998; Frost et al. 2000;

Frost et al. 1997). Similarly, in Arabic, a word was shown to be primed by a different word with the same root (Perea et al. 2010, Experiment 2). This is in contrast to the findings in work by Forster (1987) for English in which form-based priming did occur, but not morphological priming. Together, these results indicate a morphological component to reading in templatic languages with the root playing a key role such as one where words are stored and accessed by the root. That is, while stems such as the English word string are un-parseable and holistically processed, Semitic stems like the Hebrew word MiKTaV (postal letter) may be broken up in the early word recognition lexical access stage into the root K.T.V. and the template Mi__ a_.

In addition to roots and templates, Hebrew words may be rendered more complex in morphological terms by the addition of affixes. For example, affixing TI (1sg) to the word KaTaV (*write*) creates the word KaTaVTI (*I wrote*). Previous research on concatenative languages, such as English, has shown evidence of morphological parsing of morphologically complex affixed words during lexical access. Among other types of evidence, Taft (1979, 2004) found longer reaction times for morphologically complex words compared to simple ones (.e.g. walk+ing vs walk). The increased reaction time is interpreted as evidence of readers' parsing the complex words into their constituent morphemes in lexical access. Affixed words in Hebrew may also require longer RTs in a way that parallels complex morphemes in English, but no research to date has investigated the role of morphological complexity resulting from affixation in lexical access in Semitic languages. Given the distinct morphological structure of Semitic languages, comparing the processing of morphologically complex (affixed) words versus simple (un-affixed) ones in Hebrew, through reaction times, needs to be investigated. No previous work has compared reaction times in reading words of varying complexity due to affixation in Hebrew. Factors such as frequency are also thought to play an important role in whether or not parsing occurs (Alegre and Gordon, 1999).

4.3 Study 1: Transpositions in Root versus Template Morphemes

In Study 1, I compare flexibility in processing of root information with that of template information during lexical access in a masked priming paradigm. Previous work has shown that for nouns only roots and not templates prime Frost et al. (1997) as discussed in Chapter 3. In this study, I investigate whether this relates to letter position flexibility and the role of the root in recognition of noun words. I do this by first testing whether primes with transposed root letters (TL) prime (Experiment 1), thereby replicating findings for Hebrew and Arabic (Velan and Frost 2011; Perea et al. 2010). This then serves as a baseline for the next experiment testing whether TL of template letters primes successfully (Experiment 2). Due to the differing morphological roles of root and template letters, I expect priming to occur in Experiment 2 despite transposition. That is, two different processing mechanisms are predicted for the two parts of the stem, root vs. template, resulting in differences in priming patterns. This result would indicate a parsing of these two elements during lexical access. Experiment 3 tests whether TL of a root with a template letter primes. Because the transposition involves letters associated with different morphological roles and involves root letters in the process, I predict that root-template TL will fail to prime. Experiments 2 and 3 also include a preliminary investigation of morphological parsing of affixed words in Hebrew comparing RTs for affixed and un-affixed words matched in length and frequency. I expect a longer RT for affixed than un-affixed words as was found for concatenative languages. Finally, Experiments 2 & 3 investigate whether position of transposing (initial versus medial) has an effect in Hebrew and whether word length can mediate this as it has in other languages (Schoonbaert and Grainger 2004 [French]). I predict that initial transposition in Hebrew will slow RTs as in other languages and that longer words will help mitigate these effects.

4.3.1 Methodological Considerations

Letter transposition priming effects have been shown to be diminished at word boundaries; both word initially (Guerrera and Forster 2008 [English]) and word finally (Perea et al.

2003 [Spanish]). In 7 letter words, some priming effects are maintained, while in 5 letter ones they are not (Schoonbaert and Grainger 2004 [French]). That is, while typically longer words might have longer RT, in the case of TL primes, longer words had shorter RTs that make up for any initial effects. The initial effect presents a potential problem with designing Hebrew stimuli for Experiment 2 as consecutive template consonants appear for the most part on the word edges and words are typically no longer than 6 letters long.

Two precautions are taken in the effort to prevent or diminish any potential initial effects. Firstly, for both experiments, there is both a 5 and 6 letter condition to control for and investigate the possible interaction between word length and position effects. Secondly, another 6 letter affixed condition is used in Experiment 2 with a bound single letter morpheme added to the beginning of a five-letter word. This increases the morphological complexity of the words, but ensures that transposition does not occur word initially. In all cases, transpositions do not occur across morpheme boundaries, which has been shown to significantly reduce priming (Christianson et al. 2005 [English]; Duñabeitia et al. 2007 [Spanish, Basque]). The use of both complex and non-complex words also allows for the comparison of processing between the two as described briefly above. Specific predictions for these conditions are laid out in the experiments below.

In studies on other languages, transpositions with vowels (Perea and Lupker 2004 [Spanish]) and non-adjacent letters (Perea et al. 2008 [Spanish]) have been shown to have lesser TL effects and were avoided here. All transpositions were made between adjacent consonants.

4.3.2 Experiment 1: Root Transpositions in Nouns Replication and Extension of Previous Findings

This experiment tests the flexibility in the lexical access stage of reading through masked priming with transposed root letters in Hebrew in partial replication of Velan and Frost (2009) study. The methodology of this and the subsequent experiments are nearly identical to that of Velan and Frost (2009) in terms of mask type, presentation time for mask and prime. I expect no priming in the TL condition with RTs similar to controls.

The effect of word length on RT is also explored between five and six letter words. Velan and Frost (2009) stimulus words were between four and six letters long and thus this length distinction is not expected to affect results of TL priming. I predict longer RTs for six than five letter words in line with previous research showing longer words take longer to read in lexical decision tasks in other languages (e.g. Balota et al. 2004).

Methods

Participants

Twenty native Hebrew speakers between the ages of 19-46 living in the United States 0-15 years, most (>70%) having lived in the U.S. 3 years or less, participated in this experiment. They had normal or corrected to normal vision and came from a wide variety of backgrounds including students, stay at home spouses, researchers and engineers. Compensation was offered for participation. All participants were asked to complete a short demographic and language survey before beginning the study and asked to read a short passage and answer some questions to help verify basic Hebrew reading fluency and to identify potential reading disorders. All 20 subjects participated in this experiment and experiment 2 and 3, as well as two other experiments and another language survey for a different study.

Stimuli

5-Letter Condition. Targets are 24 nouns (length 5 letters, frequency 1-25, average 5.00) that were primed by one of three prime types: (1) identical (ID), (2) transposed and (3) unrelated (UR non-word). Transpositions (TL) were made word internally between adjacent root consonants, randomly varying whether transposition was between the 1st and 2nd or between the 2nd and 3rd letters of the root (Table 7.2)¹. Frequency for these and all other stimuli were obtained via The Word Frequency Database for Written Hebrew (Frost et al. 2005).

¹Original Hebrew stimuli are available for this and all other experiments upon request.

6-Letter Condition. Targets are 24 words (length 6 letters, frequency 1-25, average 5.00).

Non-Words A total of 48 non-words with matching length (24 five-letter and 24 six-letter) constituted fillers. These were similarly primed by ID, UR and TL primes with any transpositions corresponding to transpositions in the words.

TABLE 4.1: Stimuli for Study 1-Experiment 1: Root Transpositions in Nouns

<i>5-Letter</i>			
	Identity	TL	Unrelated
Prime	TiZKoReT	TiKZoReT	KaTSaBaH
	TZKRT	<u>TKZRT</u>	KTSBH
Target	TiZKoReT	TiZKoReT	TiZKoReT
	TZKRT	TZKRT	TZKRT
<i>6-Letter</i>			
	Identity	TL	Unrelated
Prime	TaXLUFaH	TaLXUFaH	MiSROLeT
	TXLUFH	<u>TXLUFH</u>	MSROLT
Target	TaXLUFaH	TaXLUFaH	TaXLUFaH
	TXLUFH	TXLUFH	TXLUFH

An example word meaning ‘reminder’ or 5-letter and ‘exchange’ for 6-letter with the three possible primes. Bolded italicized letters are the root letters. Transposed letters are underlined.

Procedure

Participants were asked to perform a lexical decision task, discriminating words from non-words. The participants were tested in quiet rooms in locations convenient for the sub-

ject using the same computer. The stimuli were presented using PsychoPy software (Peirce 2008, 2007). RTs were measured from presentation of the target to reaction using an io-Lab button box with 1 millisecond timing resolution connected to the laptop through USB. Stimuli appeared at the center of the screen starting with 7 hash marks (#####) for 500 ms, followed by a prime for 40 ms and then immediately followed by the target which remained on the screen until participants reacted. Prime and Target words were presented in David font, with Targets 25% larger than Primes to set them apart. Participants were instructed to press a ‘yes’ button if the target was a word and a ‘no’ button if it wasn’t one. There was a 1000 ms lag to the next stimulus after each button press. Buttons were on opposite sides of the button box and labeled. Participants were instructed to answer as quickly as possible and in case of mistake to continue without pause. They were not explicitly informed of the existence of the prime until after the completion of the experiment. All words and non-words of all of the lengths were presented as one experiment. Three lists were constructed in a Latin square design to ensure that each word was primed by each of the different prime types (ID, TL and UR) across subjects. For each participant, all of the target words and non-words were randomly shuffled and sorted with their respective primes with not more than two words or non-words appearing in a row to prevent habituation. A break was given after every 24 target words, when a smiley face icon appeared in the center of the screen (:)) for 5 seconds, followed by a 5 second backward countdown. For each experiment, participants were informed of the number of breaks for that task and advised to take advantage of the opportunity to stretch and look away from the screen. Stimuli presented after the break were always non-words.

Analysis

All data were analysed using linear effects mixed models in order to take into account both the random effects of Subject and Item and the fixed effects of prime-type (ID, TL or UR) and word-type (5-letter, 6-letter). Trials in which subjects made an error in lexical decision were excluded from the analysis. Data were analyzed in R (Pinheiro et al. 2009) using the

R packages lme4 (Bates et al. 2013) and languageR (Baayen et al. 2011;Baayen 2008), with p-values obtained using the lmerTest (Kuznetsova et al. 2014) package. Normality and Homogeneity were verified by visual inspections of plots of residuals against fitted values. Likelihood ratio tests comparing the models with fixed effects to null models with only random effects were performed to determine the validity of a linear mixed effects model. Results in which the fixed effects model did not differ from the null model were rejected. In this study, I present p-values, significant at $p \leq 0.05$ as well as the t-values.

Results

Root TL The average RT across subjects for target words was measured against the control condition, UR primes. Words primed by ID type primes had on average 38ms shorter RT than controls ($t = -2.65$, $p < .008$), while those primed by TL primes had an average 21 ms shorter RT ($t = -1.251$, $p < .211$) (as shown in Table 4.2). The average error rate across subjects is 1.88% for words and 3.13% for non-words.

2.2.3 Word Length The average RT for 6 letter words is 30ms longer than 5 letter words ($t = 2.56$, $p < .011$).

TABLE 4.2: Prime times for target words in Experiment 1. Priming as compared to unrelated.

	ID	TL	UR
RT (ms)	709	726	747
Priming	+38*	+21	

* $p < .05$

Discussion

The results of this experiment are in line with the results obtained by Velan and Frost in their previous work (Velan and Frost 2009, 2011). Primes with their root letters transposed did not facilitate priming (Table 4.2) as predicted. Since the only difference between this replication and the previous experiments (Velan and Frost 2009, 2011) was the addition of the variable of word-length, these results can be used as a link with the previous work and a comparison point to the other experiments in this study. There was a significant difference for word length between five and six letter words as predicted, with six letter words taking on average longer time to process.

4.3.3 Experiment 2: Templates Transpositions in Verbs

Experiment 2 tests primes with transpositions between two adjacent template consonants with root letters remaining in place (see Tables 4.3, 4.4). This type of transposition has not been previously tested in Hebrew or in Arabic. The main question being addressed is whether roots and templates are processed differently in terms of letter flexibility and whether keeping root information intact and transposing only template letters allows for successful priming. Given that root information in particular has been shown to be important to Semitic lexical access, I predict that priming will occur as long as root consonant order remains intact. Length effect is tested as in Experiment 1.

Finally, this experiment investigates whether affixed words in Hebrew result in longer RTs as compared to un-affixed words of the same length. In line with research from other languages (e.g. Duñabeitia et al. 2007; Taft 2004) it is expected that the more complex words will have longer RTs. If initial effects significantly increase RT as in non-Semitic languages (e.g. Guerrero and Forster 2008 [English]), it is possible that the un-affixed words will have longer RTs since the transpositions in these words occur word-initially.

Note that this experiment uses verbs and not nouns as in the other experiments in this study or those done by Velan and Frost. The reason for using verbs here was purely pragmatic

in that it is difficult to find nouns with two adjacent template consonants. This does create a potential confound however in that not only the type of transposition, but also the part of speech differs in this experiment.

Methods

Stimuli

5-Letter Condition. Targets are 24 verbs (length 5 letters, frequency 1-20, average 4.92). The TL prime is made through transpositions between a word initial non-root consonant and an adjacent non-root consonant (Table 4.3).

6-Letter Condition. Targets are 24 verbs (6 letters, frequency 1-26, average, 4.04).

6-Letter Prefixed Condition. Targets are 24 5-letter verbs preceded by a bound preposition morpheme ‘l’- meaning ‘to’ (frequency 1-19, average 4.79). Transpositions occur word internally, albeit still at the edge of a morpheme.

Non-Words. Stimuli are 72 non-words, primed identically to their word counterparts. Non-words were matched to the words in length and structure, including having an equal number of non-words consisting of 6 letters with the first being a ‘l’ to match the prefixed condition.

TABLE 4.3: Stimuli for Study 1-Experiment 2: Template Transpositions in Verbs

<i>5-Letter</i>			
	Identity	TL	Unrelated
Prime	MiT K aLeaX	Ti M KaLeaX	Hi L GaMeS
	MT KLX	<u>TM</u> KLX	HL GMS
Target	MiT K aLeaX	MiT K aLeaX	MiT K aLeaX
	MT KLX	MT KLX	MT KLX
<i>6-Letter un-affixed</i>			
	Identity	TL	Unrelated
Prime	MiT Y YaXeS	Ti M YYaXeS	MeX U NeGeT
	MT Y YXS	<u>TM</u> Y YXS	MX U NGT
Target	MiT Y YaXeS	MiT Y YaXeS	MiT Y YaXeS
	MT Y YXS	MT Y YXS	MT Y YXS
<i>6-Letter affixed</i>			
	Identity	TL	Unrelated
Prime	LeHi T HaPeX	LeTi H HaPeX	AV O KSO
	LH T HPX	<u>L</u> T HHPX	AV O KSO
Target	LeHi T HaPeX	LeHi T HaPeX	LeHi T HaPeX
	LH T HPX	LH T HPX	LH T HPX

Example words with three possible primes. Bolded italicized letters are the root letters. Transposed letters are underlined.

Procedures.

Procedures are the same as in Experiment I.

Analysis

All analyses performed were the same as in Experiment I, the only difference being that the possible word types for word-type fixed effects were 5-letter, 6-letter initial TL and 6-letter prefixed medial TL.

Results

Non-Root TL

The average RT across subjects for target words was measured against the control condition, UR primes. In comparison, words primed by ID type primes had on average 42ms shorter RT ($t=-3.21$, $p < .0014$), while those primed by TL primes had an average 46ms shorter RT ($t=-3.58$, $p_{MCMC} < .0004$) (as shown in Table 4.4). Difference between ID and TL RTs is not significant. The average error rate across subjects is 0.55% for words and 1.55% for non-words.

TABLE 4.4: Mean RTs for target words in Experiment 2. Priming as compared to unrelated.

	ID	TL	UR
RT (ms)	700	696	742
Priming	+42*	+46*	

**p < .05*

3.2.3 Word Length The average lexical decision RT for 5 letter words is 2ms longer than for 6 letter words ($t=.133$, $p < .895$) (See Table 4.5).

3.2.4 Morphological Complexity/Transposition Position On average, the RT for 6 letter prefixed words (those in which TL is in medial position) is 43ms longer than those of 6 letter un-prefixed words (those in which TL is in initial position) with ($t=3.14$, $p < .0024$) (See Table 4.5).

TABLE 4.5: Average difference in RT between 6 letter initial condition and other conditions.

	5 un-affixed	6 letter affixed
Diff RT from 6 letter un-affixed	-2	-43*

* $p < .05$ *Discussion*

I predicted that priming would occur with transposition of two non-root letters and the results confirmed this (Table 4). This supports the claim that root letters serve a special function in Hebrew lexical processing. Furthermore, it indicates a flexibility in template letter position, similar to that of concatenative languages. The priming effect is larger here than in Experiment 1, which may be due to the difference in part of speech. There was no significant difference observed between reaction times for five letter versus six letter un-affixed words contrary to our hypothesis that longer words would have shorter reaction times due to mediation of initial effects (Table 4.4). The lack of difference may be due here to the nature of the stimuli, which often included double letters creating a single sound (Table 4.3) which may have mediated the length effect. Additionally, it is possible that this is a result of the relatively small difference in length between the long and short conditions of just one letter (versus the three letter difference between four and seven letter words in Schoonbaert and Grainger 2004). Similarly, the benefit of length to mediate initial effects may only be significant with seven letter words. Since un-affixed Hebrew words of that length are rare, seven letter stimuli were not included in either this or previous works (Velan and Frost 2009, 2011).

As predicted, there was an effect of morphological complexity on word length. Six letter un-affixed words had shorter reaction times on average than six letter affixed words. This supports a theory of longer processing time for morphologically complex words to allow time

for parsing into constituents (Duñabeitia et al. 2007; Taft 1979, 2004). Further research should be done to investigate processing of affixed and un-affixed words in Hebrew, looking at effects of frequency and neighborhood density. Our results show no indication of initial TL effects or at least strong initial effects since the un-affixed words with initial TL had shorter reaction time than the affixed ones with medial TL. However, since the reaction times are averaged between an equal number of the TL, Identity and Unrelated primed words in this model, any initial effects may be masked by the averaging. It is also possible that the initial effect is masked if the complexity effect is much greater i.e., less time is added due to initial TL than is added due to morphological parsing of affixed words in the affixed condition. Finally, it is possible that initial effects are morpheme initial and not word initial in which case the added morpheme does not eliminate the initial factor.

4.3.4 Experiment 3: Root and Template Transpositions in Nouns

In this experiment a root and a template letter were transposed. Root letters retained their relative order to one another. These transpositions do not form existing words.² The length and complexity manipulations are the same as in Experiment 2. I predict that transpositions involving root letters would fail to prime. I also predict that more complex (affixed) words would take longer to read than un-affixed words and that longer words (6 letters) would take longer to read than shorter ones (5 letters).

Methods

Stimuli

5-Letter Condition. Targets are 24 nouns (length 5 letters, frequency 1-20, average frequency 5.25). TL primes are made through transpositions between a word initial non-root

²This is in contrast to the Perea et al. (2010) study in Arabic in which root and template letters were transposed to form an existing word with the same root. A manipulation with a shared root creates a potential confound given that root priming has been shown for nouns in Hebrew Frost et al. (1997) Thus any priming effects can be due to letter position flexibility or root priming

consonant and an adjacent root consonant (Table 4.6).

6-Letter Condition. Targets are 24 nouns (length 6 letters, frequency 1-13, average 5.25).

6-Letter Prefixed Condition. Targets are 24 5-letter nouns preceded by a bound definite determiner morpheme meaning *the*; ‘h-’ in English transcription. All transpositions occur word internally, albeit still at the edge of a morpheme (length 6 letters, frequency 1-20, average 5.25).

Non-Words. Stimuli are 72 non-words, primed identically to their non-word counterparts. Non-words are matched to words in length and structure, including having an equal number of non-words consisting of 6 letters with the first being a ‘h’ to match the prefixed condition.

TABLE 4.6: Stimuli for Study 1-Experiment 3: Root and Template Transpositions in Nouns

	Identity	TL	Unrelated
Prime	MaXMaAH	XaMaMaAH	SaKXIN
	<i>MXMAH</i>	<i><u>X</u>MMAH</i>	SKXIN
Target	MaXMaAH	MaXMaAH	MaXMaAH
	<i>MXMAH</i>	<i>MXMAH</i>	<i>MXMAH</i>

An example word meaning ‘a complement’ with its three possible primes. Bolded italicized letters are the root letters. Transposed letters are underlined.

Procedures.

Procedures are the same as in Experiments 1 and 2.

Analysis

All analyses performed were the same as in Experiments 2.

Results

Root with Non-Root TL

The average RT across subjects for the target words was measured against the control condition, UR primes. In comparison, words primed by ID type primes had on average 46ms shorter RT ($t = -2.989$, $p < .003$), while those primed by TL primes had an average 21ms shorter RT ($t = -1.386$, $p_{MCMC} < .166$) (as shown in Table 4.7). The average error rate across subjects is 1.60% for words and 1.65% for non-words.

TABLE 4.7: Mean RTs for target words in Experiment 3. Priming as compared to unrelated.

	ID	TL	UR
RT	748	773	794
Priming	+46*	+21	

**p < .05*

Word Length

The average lexical decision RT for 5 letter words is 25 ms shorter than for 6 letter words ($t = -1.667$, $p < .096$) (See Table 4.8).

Morphological Complexity/Transposition Position

On average, RTs for 6 letter prefixed words (TL in medial position) is 37 ms shorter than those of 6 letter un-prefixed words (TL in initial position) with ($t = -2.473$, $p < .0135$) (See Table 4.8).

TABLE 4.8: Average difference in RT between 6 letter initial condition and other conditions.

	5 un-affixed	6 letter affixed
Diff RT from 6 letter un-affixed	+25	+37*

* $p < .05$ *Discussion*

As predicted, words with transpositions of a root letter and template letter did not prime. This serves as further support of the importance and inflexibility of root letters. Even while maintaining relative root letter order, transpositions involving root letters inhibit reading.

As with Experiment 2, there was no significant effect of length observed in this study. Reading five letter words was not significantly faster than reading six letter words (Table 8).

Affixed six letter words had significantly shorter reaction times than un-affixed words. This was contrary to the predicted outcome and also different than the observation in Experiment 2. Further investigation would need be conducted to understand this difference given that reading of only two affixes are observed in these experiments, the preposition 'l'- meaning to used with verbs in Experiment 2 and the definite marker 'h'- synonymous with the used with nouns in this experiment. The longer reading times with the 'l'- affixes in Experiment 2 are as predicted with a parsing account as discussed above. One possible account is that the 'h'- prefix helps to speed up access to words by limiting competitors. A word initial 'h'-, if not part of a root or template is necessarily the determiner, which must precede a noun. The prefix 'l'- in contrast can be attached both to verbs (e.g. to walk) and nouns (e.g. to [a] store). A further study should be conducted looking at reading affixed words in Hebrew with more affix types and controlling for parts of speech.

4.4 Study 2: Transpositions in Roots and Templates in Nouns vs. Verbs

Study 2 seeks to extend and further explore issues from Study 1. Using the same paradigms of letter transposition and masked priming, this study investigates whether flexibility depends on part of speech (noun vs. verb).

4.4.1 Methodological Considerations

Unrelated Condition

In letter flexibility studies looking at concatenative languages, unrelated primes are identical to the transposed letter primes except that the letters of interest are substituted instead of transposed (e.g. for the word *string*, the TL condition would be *srtng* and the unrelated would be *skling*). This is important in concatenative languages to distinguish from priming (e.g. *strange* priming *strong* due to the orthographic overlap) from letter position flexibility where the original word order is recovered. If the effect is just a result of form priming, then both the unrelated and transposed letter manipulations would prime and since the unrelated is the point of comparison no priming effect would be observed. In contrast, if priming was due to letter position flexibility, the reader would recover the word in the TL condition, which would have a stronger priming effect than in the unrelated condition.

However, since form-priming does not occur in templatic languages, it is not crucial for unrelated primes to be substitutions of the transposed letters. Thus in Study 1, primes in the unrelated condition are non-words which do not overlap in phonological form with the target. However, in Study 2, the unrelated primes are identical to the transposed letter prime with substitutions. This is done to distinguish priming which may occur due to recognition of either the root or the template only (root or template priming) from recovery of the whole word (letter position flexibility).

Log Transforming Reaction Times

A linear mixed effects model assumes normalized distribution of variables. As a result, if a dependent variable such as RT is not normally distributed, a manipulation such as a log

transformation is necessary. As linear mixed effects models become more commonly used, RT data has begun to be log transformed in cases where it is not normally distributed. This was the case for one of the experiments below. In order to address this, reaction times for that experiment were log transformed before assessing significance for priming effects. Since log transformed RTs are used for one of the experiments, I additionally report the p values obtained with log transforms of RT for all of the other experiments. As expected, significance values obtained with normalized and actual RTs for those other experiments do not differ.

4.4.2 Experiment 1: Root Transpositions in Nouns vs. Verbs

Experiment 1 compares root transpositions in nouns and verbs. Previous work on Hebrew and Arabic has focused on noun stimuli. As described in Chapter 2, nouns and verbs differ with respect to morphology in Hebrew. While there is a closed class of seven verb templates, the number of noun templates is far greater, numbering at least a hundred. Furthermore, while root priming is possible for both roots and nouns, only verbs can be primed by a shared template (Deutsch et al. 1998). The question being investigated here is whether letter position flexibility is different for nouns and verbs in Hebrew. In particular, I predicted that due to the small closed class of templates in verbs and the possibility for template priming, verbs with root letters transposed could prime. On the other hand, it is possible that letter flexibility effects would apply to both verbs and nouns since the root plays an important role for each of these.

Methods

Participants

Participants are 26 native Hebrew speakers age 18 to 54, all but four of whom live and were tested in Israel. Four of the subjects live in the United States and were tested there. They had normal or corrected to normal vision and came from a wide variety of backgrounds including students, graphic designers, researchers and engineers. Compensation was offered for participation. All participants were asked to complete a survey before beginning the

study to answer some demographic questions and questions about reading habits. All 26 subjects participated in all experiments in Study 2. Subjects were presented the experimental items in a systematically varied order to avoid effects of order of presentation.

Stimuli

Nouns Stimuli consisted of 24 target nouns that were primed by one of three prime types: (1) identical (ID), (2) transposed (TL), and (3) unrelated (UR non-word). Transpositions were made word-internally between adjacent root consonants, varying whether the transposing was between the 1st and 2nd or between the 2nd and 3rd letters of the root. Table 4.9 illustrates the three prime types with examples. The lexical frequency of the words ranged from 1-15, with an average frequency of 4.92. Frequency for these and all other stimuli were obtained via The Word Frequency Database for Written Hebrew (Frost and Plaut (2005)). Words are between 4 and 5 letters in length.

Verbs Stimuli were 24 target words and primes, in an identical paradigm as to the one above except that all stimuli were verbs. The lexical frequency of the words ranged from 1-14, with an average frequency of 4.50.

Non-Words There were 48 non-words. Non-words were matched in length, and structure to the words.

TABLE 4.9: Stimuli for Study 2-Experiment 1: Root Transpositions in Nouns vs. Verbs

<i>Nouns</i>			
	Identity	TL	Unrelated
Prime	MaXSOM	MaSXOM	MaHDOM
	MXSOM	MSXOM	MHDOM
Target	MaXSOM	MaXSOM	MaXSOM
	MXSOM	MXSOM	MXSOM

<i>Verbs</i>			
	Identity	TL	Unrelated
Prime	HiTNaGeD	HiTGaNeD	HiTBaReD
	HTNGD	HTGND	HTBRD
Target	HiTNaGeD	HiTNaGeD	HiTNaGeD
	HTNGD	HTNGD	HTNGD

Example words for noun ('barrier') and verb ('to object') with three possible primes. Bolded italicized letters are the root letters. Transposed letters are underlined.

Procedure

The experiment was administered on the same computer in a quiet location, convenient for the subject. The Stimuli were presented using PsychoPy software (Peirce 2008, 2007). ioLab button box with 1 millisecond timing resolution was used to measure RTs from stimuli presentation to button press. Stimuli were presented at the center of the screen. First subjects saw the forward mask of seven hash tags (#####) followed by the prime for 40ms and then finally the target word which remained on the screen until button press. There is a 1000ms ISI between button press and the next stimuli. Primes and targets were presented in David font. Since there is no capitalization distinction in Hebrew, targets were

set 25% larger than primes to set them apart. Participants were instructed to make a lexical decision as quickly and accurately as possible by selecting the ‘yes’ button if a subject was a word and the ‘no’ button if it is wasn’t a word. Participants were instructed to continue without pause in case of a mistake. They were not informed in advance of the existence of the primes.

All words and non-words were presented together acting as fillers for one another. Three lists were constructed in a Latin square design to ensure that each word was primed by each of the different prime types (ID, TL and UR) across subjects. Subjects had a 10 second break after every 24 words consisting of a smiley face for 5 seconds and backwards countdown for another 5 seconds. Participants were informed about the breaks and encouraged to use the time to stretch and look away from the screen. The item immediately following a break was always a non-word.

Analysis

All data were analysed using linear effects mixed models in order to take into account both the random effect of Subject and the fixed effects of prime-type (ID, TL or UR). Trials in which subjects made an error in lexical decision were excluded from the analysis. Additionally, RTs outside of 2 standard deviations of average reaction time for a subject were removed. Data were analyzed in R (Pinheiro et al. 2009) using the R packages lme4 (Bates et al. 2013) and languageR (Baayen et al. 2011; Baayen 2008), with p-values obtained using the lmerTest (Kuznetsova et al. 2014) package. Normality and Homogeneity were verified by visual inspections of plots of residuals against fitted values as well as box and whisker plots. If RTs were not normally distributed, RTs were normalized through log transform and p values were obtained from normalized RT. If log RTs were used for any of the experiments, p values were additionally calculated for log RTs for all experiments. Likelihood ratio tests comparing the models with fixed effects to null models with only random effects were performed to determine the validity of a linear mixed effects model. Results in which the fixed effects model did not differ from the null model were rejected. In this study, I present p-values,

significant at $p \leq 0.05$ as well as the t-values.

Results

Nouns

The average RT across subjects for target words was measured against the control condition, UR primes. In comparison, words primed by ID type primes had on average 67 ms shorter RT ($t = -3.446$, $p < 0.0006$), while those primed by TL primes had an average 3 ms longer RT ($t = 0.169$, $p\text{MCMC} < .867$) (as shown in 4.10). The average error rate across subjects is for words is 2.40%.

Verbs

The average RT across subjects for target words was measured against the control condition, UR primes. In comparison, words primed by ID type primes had on average 98 ms shorter RT ($t = -5.892$, $p < 6.92e-09$), while those primed by TL primes had an average 60 ms shorter RT ($t = -3.533$, $p\text{MCMC} < 0.00045$) (as shown in 4.10). The average error rate across subjects is 4.65% for words.

Log RT

With log RTs with nouns, for ID primes $t = -4.769$ $p\text{MCM} < 2.4e-06$; in the TL condition $t = -0.280$ and $p\text{MCM} < 0.779$. Verbs with ID primes $t = -6.333$ and $p\text{MCM} < 5.24e-10$ and for TL $t = -3.469$ and $p\text{MCM} < 0.0006$.

Discussion

Results from priming with transposed root letters in nouns replicated the results of Velan and Frost (2011, 2009) as predicted. Verbs with transposed root letters did prime on the other hand. Given that roots prime both roots and nouns, but templates prime verbs alone (Frost et al., 1997; Deutsch et al., 1998), a difference in processing verbs and nouns is not unexpected. However, understanding the reason for the flexibility in this case would require further investigation. The difference between verbs and nouns may be a product of the

TABLE 4.10: Mean RTs for target words in Experiment 1. Priming as compared to unrelated.

Nouns

	ID	TL	UR
RT	680	751	748
Priming	+68*	-3	

* $p < .05$

Verbs

	ID	TL	UR
RT	660	698	758
Priming	+98*	+60*	

* $p < .05$

difference in productivity of their respective templates. As described above, verbs have far more productive and limited templates. This limited number of templates may play a role in letter position flexibility. Decreasing the load on recovery of the template, may make root recovery easier. Note that, the priming effect cannot be attributed to template priming since the unrelated condition has the same template as well with just root letters manipulated (see Table 7.2).

The difference in letter position flexibility between verbs and nouns does further the argument that the inflexibility is related to morphology. The fact that part of speech plays a role here strengthens the argument that the effect is not orthographic in nature. In terms of orthography, verbs and nouns do not differ and the stimuli were matched for both length and frequency.

4.4.3 *Experiment 2: Root and Template Transpositions in Nouns vs. Verbs*

In this experiment adjacent root and template letters are transposed, maintaining relative root letter order but changing the position. The goal of Experiment 2 is to investigate whether part of speech plays a role in transpositions between root and template letters. That is, would letter position flexibility effects differ depending on whether the target is a noun or a verb?

I predicted that TL of root and template letters in a noun would not prime just as in Study 1 (see Section 4.3.4). With this manipulation, I did not predict that verbs would be less sensitive to letter position flexibility. Verbs processing appears to strongly involve both the root and template as evidenced by priming possible by each of these (Deutsch et al. 1998). Thus a transposition between root and template letters would be predicted to be especially damaging for verbs since both the root and template are affected.

Methods

Stimuli

Nouns Stimuli consisted of 24 target nouns that were primed by one of three prime types: (1) identical (ID), (2) transposed (TL), and (3) unrelated (UR non-word). Transpositions were made word internally between two adjacent template and root consonants. Table 4.11 illustrates the three prime types with examples. The lexical frequency of the words ranged from 1-19, with an average frequency of 4.83. Words are between 4 and 5 letters in length.

Verbs Stimuli were 24 target words and primes, in an identical paradigm as to the one above except that all stimuli were verbs. The lexical frequency of the words ranged from 1-16, with an average frequency of 4.08.

Non-Words There were 48 non-words. Non-words were matched in length, and structure

to the words.

TABLE 4.11: Stimuli for Study 2-Experiment 2: Root and Template Transpositions in Nouns vs. Verbs

<i>Nouns</i>			
	Identity	TL	Unrelated
Prime	MaXBeT	XaMBeT	LaDBeT
	MXBT	<u>XMBT</u>	LXBT
Target	MaXBeT	MaXBeT	MaXBeT
	MXBT	MXBT	MXBT

<i>Verbs</i>			
	Identity	TL	Unrelated
Prime	HeKTIN	KeHTIN	NeSTIN
	HKTIN	<u>KHTIN</u>	NSTIN
Target	HeKTIN	HeKTIN	HeKTIN
	HKTIN	HKTIN	HKTIN

Example words with three possible primes. Bolded italicized letters are the root letters. Transposed letters are underlined.

Results

Nouns

The average RT across subjects for target words was measured against the control condition, UR primes. In comparison, words primed by ID type primes had on average 53ms shorter RT ($t=-2.836$, $pMCM < 0.005$), while those primed by TL primes had an average 43ms longer RT ($t=-2.267$, $pMCMC < 0.02379$) (as shown in 4.12). The average error rate across subjects is for words is 4.17%.

Verbs

The average RT across subjects for target words was measured against the control condition, UR primes. In comparison, words primed by ID type primes had on average 48ms shorter RT ($t=-2.784$, $pMCM < 0.006$), while those primed by TL primes had an average 15ms shorter RT ($t=-0.855$, $pMCM < 0.393$) (as shown in 4.12). The average error rate across subjects is 2.88% for words.

TABLE 4.12: Mean RTs for target words in Experiment 2. Priming as compared to unrelated.

Nouns

	ID	TL	UR
RT (ms)	717	727	770
Priming	+53*	+43*	

* $p < .05$ *Verbs*

	ID	TL	UR
RT (ms)	682	715	730
Priming	+48*	+15	

* $p < .05$

Log With log RTs with nouns, for ID primes $t=-3.814$ $pMCM < 0.0002$; in the TL condition $t=-2.731$ and $pMCM < 0.007$. Verbs with ID primes $t=-3.362$ and $pMCM < 0.00083$ and for TL $t=-1.335$ and $pMCM < 0.182$.

Discussion

As predicted, verbs with a transposed root and template letter did not prime. This is in line with both a root and template playing a parallel role in reading verbs. A transposition

between a root and a template letter would make it more difficult to recover both a root and a template. Nouns with root and template letters transposed did not behave as expected. A noun with a transposed root and template letter did prime. This may be because for noun recognition, the important information to recover is the root first and foremost. Thus, a transposition leaving relative root order intact may allow for easier recovery of the root.

The noun result is not the same as in Study 1 in which nouns with root and template letters transposed did not prime. This difference cannot be attributed to the difference in type of unrelated prime (unrelated non-word in Study 1 versus substituting letters in Study 2) since this would predict a greater effect for Study 1 than Study 2 given the bigger difference between the unrelated and TL conditions. In fact the difference in reaction time between the unrelated and the TL and identity primes is greater in magnitude in Study 2 than in Study 1 so unrelated prime type is not likely the cause.

One possible explanation for the difference in priming is a lack of power in Study 1 with only 20 subjects versus the 26 in Study 2. TL-primed targets had on average a 21 ms shorter RT than UR, however it was not significant (see Table 4.7). Furthermore, there were length and affixation variables present in Study 1, while these are not included in Study 2, which also decrease power. Further investigation is necessary to understand the difference in findings.

4.4.4 Experiment 3: Template Transpositions in Verbs

Experiment 3 is a replication of Experiment 2 in Study 1 with transpositions occurring between two template letters in a verb. In this experiment, UR primes were identical to TL primes except the letters that were transposed in the TL condition were substituted instead. This is in contrast to the UR primes in Study 1 that had no overlap in form with the target. With this type of prime it is possible to evaluate whether readers are actually recovering the word as a whole. It excludes the possibility that priming is due to recovery of the root alone since both UR and TL primes contain the root letters in the same position. I predicted that with a TL between template letters, the word would be recovered and priming would occur.

Methods

Stimuli Stimuli consisted of 24 target verbs that were primed by one of three prime types: (1) identical (ID), (2) transposed (TL), and (3) unrelated (UR non-word). Transpositions were made word internally between two adjacent template consonants. Table 4.13 illustrates the three prime types with examples. The lexical frequency of the words ranged from 1-23, with an average frequency of 4.08. Words are 5 letters long.

Non-Words There were 24 non-words. Non-words were matched in length, and structure to the words.

TABLE 4.13: Stimuli for Study 2-Experiment 3: Template Transpositions in Verbs

	Identity	TL	Unrelated
Prime	HiT <i>G</i> aBeR	TiH <i>G</i> aBeR	LiM <i>G</i> aBeR
	HT G BR	<u>TH</u> GBR	LMGBR
Target	HiT <i>G</i> aBeR	HiT <i>G</i> aBeR	HiT <i>G</i> aBeR
	HT G BR	HT G BR	HT G BR

Example word with three possible primes. Example words with three possible primes. Bolded italicized letters are the root letters. Transposed letters are underlined.

Results

The average RT across subjects for target words was measured against the control condition, UR primes. In comparison, words primed by ID type primes had on average 21 ms shorter RT, while those primed by TL primes had an average 36 ms shorter RT (as shown in Table 4.14). Upon visual inspection, it was apparent that data is not normally distributed as illustrated by Figure 4.1. P values were obtained for log transformed RTs. For the ID condition, $t=$

2.844, $pMCM < 0.005$ and for the TL condition, $t = -2.487$, $pMCM < 0.0132$. The average error rate across subjects is 1.76% for words.

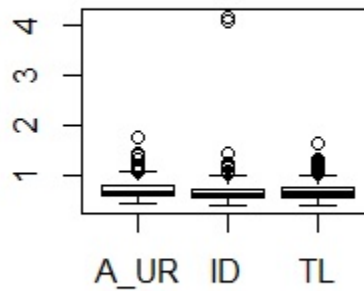


FIGURE 4.1: Box and Whisker Plot reflecting skewed distribution of RTs

TABLE 4.14: Mean RTs for target words in Experiment 3. Priming as compared to unrelated. P values obtained from logged reaction times

	ID	TL	UR
RT (ms)	690	674	711
Priming	+21*	+36*	

* $p < .05$

Discussion

As predicted, targets were primed in the TL condition. This is in line with letter position flexibility being less of a problem for verbs so long as either the root or the template is

intact. In this case, roots remain both in the same relative order and absolute position in the word. With root information readily available, word identification is possible despite the transposition in the root.

The results of this experiment also suggest that the priming effect is not simply a recovery of the root information, but actual reconstruction of the word. Despite the UR condition sharing the same root letters in the same position, a priming effect is observed in the TL condition.

4.5 Overall Discussion and Future Directions

As expected, both Study 1 and Study 2 support the role of morphological processing in Hebrew word recognition. This is in line with previous work on Semitic languages (e.g. Velan and Frost 2011 [Hebrew] and Perea et al. 2010 [Arabic]). Roots and templates morphemes are involved in word recognition and thereby limiting letter position flexibility effects. These roles appear to differ between verbs and nouns as discussed below. Hebrew also appears to have morphology play a role in reading of affixed words, just as in concatenative languages such as English (e.g. Taft 2004).

4.5.1 Reading Verbs vs Nouns

The results of this experiment and of previous work has shown two differences in the role of the root and template in noun vs. verb recognition. In particular, verbs can be primed by words sharing either roots or templates Deutsch et al. (1998) and are letter position flexible for either root or template, but not both. Nouns, on the other hand, can only be primed by roots and transpositions effecting relative root letter order inhibit word recognition. In this section, I propose two possible recognition mechanisms which might account for these differences. These are both model agnostic and could potentially be applied to any compatible reading model.

Each of my proposed mechanisms has the same presuppositions: (1) The lexicon consists of roots and templates; (2) During word recognition, roots and templates matching the input

are activated; (3) In addition, orthographic neighbor roots and templates are also activated to a lesser degree; (4) Generally verb templates are more frequent, given that there are only seven of them as compared to at least one hundred for nouns; (5) Due to the grammatical function they serve, verb templates cannot be applied to every root, rather some combinations are incompatible (e.g. The reflexive verb template HiTPaʃeL is not compatible with the root *D.B.R.* meaning *speak*, so no word HiTDaBeR is possible).

The first mechanism I propose is a probabilistic narrowing of search space during word recognition. Verb templates are recognized quickly due to their frequency and productivity. Once they are recognized, the root search space is narrowed to the roots compatible with the given template. In a transposed letter priming paradigm where root letters are transposed and only orthographic neighbor roots are (weakly) activated, this small search space helps with recognition. Thus, a verb with transposed root letters can still be identified and serve as a prime. In noun recognition, identifying the template is more difficult and does not narrow the search space as much. As a result, there is more of a chance for multiple root neighbors to be equally likely and therefore a noun with root letters transposed cannot be quickly recognized and does not prime in a masked priming paradigm.

The second mechanism I propose is an activation based mechanism compatible with word recognition models such as the Interactive Activation Model (McClelland and Rumelhart, 1981). In this framework, recognition occurs when combined activation levels for roots and templates reach a certain threshold. Activation level is modulated by orthographic overlap as well as frequency. Thus, in when root letters are transposed, the activation for the target root is weak. For verbs, however, the template activation is great due to the relative frequency of these templates. Thus, the combined activation of the template and the root is high enough to reach a threshold for recognition in spite of transposition. In contrast, the activation level of noun templates is lower due to their lower relative frequency. As a result, the combined activation level for the target root and template does not reach threshold and priming does not occur.

4.5.2 *Further Questions*

Results from Study 1, showing longer RTs for affixed words than simple words, indicate that affixed words are decomposed in Hebrew, just as in English (e.g. Taft 2004). Furthermore, the evidence from both studies suggests that all templatic Hebrew words undergo decomposition into a root and a template. Chapter 7 explores both of these possibilities with ERPs.

While the importance of the root for recognizing nouns in Hebrew has been explored in reading, previous work has not looked at writing. The goal of Chapter 5 is to further investigate this question.

Chapter 5

AUDITORY WORD RECOGNITION IN A TEMPLATIC LANGUAGE: THE ROLE OF THE ROOT

5.1 Chapter goals

This study investigates whether, as with visual lexical access, morphology plays a role in auditory lexical access in Hebrew. In order to explore this question, this study compares the success of phonemic restoration when root sounds are masked as compared to non-root sounds. The results of this study indicate the importance of morphology in auditory lexical access as well as visual. Based on findings with visual lexical access in other Semitic languages (e.g. Perea et al. 2010) it is plausible that these conclusions might be extended to other Semitic languages.

5.2 Introduction

Results from previous work and Chapter 4 gives evidence of the role of the root in visual word recognition in Hebrew nouns (e.g. Velan and Frost 2009). In reading, it possible to investigate the role of the root through transposition and letter position flexibility. This type of manipulation is not possible in auditory input, so instead I use the phoneme restoration paradigm. The goal of this study is to investigate auditory word recognition in a templatic language.

5.2.1 Visual vs. Auditory Lexical Access

The auditory and visual domain are clearly different and word recognition in each domain face its unique challenges. For instance a reader is presented with the whole word at one time, while listeners receive the phonemes of a word in sequence. Different physiological

systems are also in play with visual recognition being constrained by the visual field and properties of the retina for example. Auditory recognition instead depends on acoustic and auditory constraints.

Despite these difference, there is evidence of similarities in morphological processing in word recognition in both the auditory and visual domains. Recall that some early studies found differences between morphological processing in the auditory and visual field (e.g. Taft et al. 1986). More recent studies have found parallels in the two with decomposition effects present in both the visual and auditory domain (e.g. Leinonen et al. 2009). There are still relatively few auditory studies on morphological processing however.

Studies such as this one are important to be able to draw parallels and observe differences between the role of morphology in the auditory and visual domains. Morphological processing in word recognition has primarily focused on the visual domain. Extending this work to the auditory domain can not only reveal any parallels between the two systems, but also reveal information about modality independent morphological processing and morpheme representation in the brain.

5.2.2 Benefits of an Auditory Approach: Escape from Orthography

Aside from benefits to investigating auditory word recognition discussed in the previous section, effects found in this domain are also free of orthographic confound. One of the challenges with comparing morphological processing in visual word recognition is that it is difficult to control for effects of orthographic system.

Templatic languages in particular pose a problem due to the unique orthography of Hebrew and Arabic, which differs from that of concatenative languages. As described in Chapter 2, most vowels are omitted in written Hebrew and Arabic. Thus, these languages differ from ones like English not only in their morphological system, but also in their orthographic one. In the visual domain, there is no clear manipulation to be completely rid of this compound. The auditory domain provides an orthography free testing ground to confirm that any effects are in fact reflective of the difference in morphological structure (templatic

vs. concatenative) and not difference in orthographic system (with or without vowels).

5.2.3 *Phonemic Restoration*

Doing a completely parallel auditory replication of the visual lexical access experiments by transposing Hebrew phonemes is problematic if not impossible, given that phonemes and especially vowels carry the information of adjacent phonemes. That is, in natural speech, individual phonemes are not pronounced separately; rather phonemes co-occur or blend into one another. Properties of consonants affect adjacent vowels in various ways such as influencing relative vowel duration dependent on consonant voicing (Raphael 1972) and carrying over formant information and resonance (Cole and Scott 1974).

Therefore, rather, than transposing root consonants I mask them, in a phonemic restoration task. Phonemic restoration is the restoration of speech sound(s) that have been masked. The experiments looking at this phenomenon are typically controlled versions of the process of sound recovery that occurs naturally in noisy environments such as a café or a busy street. In those environments, a listener is often able to extract the information being relayed despite intrusion to the signal. The success of this recovery can be attributed to various top-down processes such as the use of sentential (Groppe et al., 2010), lexical information (e.g. Samuel 2001) and phonological rules (e.g. Gaskell and Marslen-Wilson 1998; Dupoux et al. (2001)). A number of experiments have looked at phonemic restoration and the factors that play a role in it including room acoustics (Srinivasan and Zahorik 2012), context (e.g. Duez 2001) and voice continuity (Clarke et al. 2014).

Masking is typically done with the use of noise, as replacing a sound with silence alone has been shown to be unnatural and difficult to recover (Kashino, 2006). As mentioned above, because vowels carry information of adjacent consonants, part of the adjacent vowel to the consonant in question is also masked in this study. Other methodologies have been used to address the issue of information transfer to the vowel including the mispronunciation of a phoneme before its deletion (e.g. Warren and Sherman 1974). Masking was chosen for this study, as mispronunciation may give competing cues to other phones which could affect

the results for this particular study where lexical access and not just phoneme restoration is being investigated.

5.2.4 Co-Articulation and Other Methodological Considerations

Co-articulation

An important methodological consideration for a masking study is accounting for co-articulation effects as described in Section 5.2.3. Co-articulation is the result of sounds being produced in sequence as is normally done, rather than in isolation. Sounds (particularly vowels and nasals) adapt to their neighboring sounds. From a physiological stand point, co-articulation is a result of anticipatory and assimilating movements. The production of a sound is affected by preparation for the next sound or by retaining some of the gestures from the previous one. Auditorily, these manifest in differences in formant frequency, length, manner assimilation such as nasalization, etc.

These effects have been widely documented across languages (e.g. Öhman 1966[Swedish, English, Russian], Recasens 1991, Farnetani and Recasens 1993 [Italian], Fowler and Saltzman 1993). Vowels in particular are sensitive to co-articulation effects (e.g. Hillenbrand et al. 2001). Perceptually, listeners become adept at picking up on co-articulation cues (e.g. Raphael 1972). Changes to formants, length etc. can help listeners perceive an adjacent sound even if that sound is not itself audible.

From a practical standpoint, this has important implications for a masking experiment. Masking any given sound is not enough, it is important that co-articulation effects are not salient in surrounding sounds as well. In this study, it is necessary to delete not only the target consonants, but also part of the neighboring vowels to avoid cues due to co-articulation. The specific manipulations are discussed in the methods section of each of the two experiments.

Masking Noise

Another methodological consideration for this study is choice of masking noise. Results

from previous experiments provide evidence that noise is a better masker than silence. White noise has been popularly employed as a masking noise. Initially this study also employed white noise for masking, however during piloting, listeners reported that listening to the white noise over headphones was uncomfortable.

An alternative type of noise called brown noise has also been used in phonemic restorations studies (e.g. Edmonds and Culling 2005). Like white noise, it carries no information that is particular to speech such as formants. However, it is more periodic and in that sense more speech-like than white noise. Brown noise was chosen for this study both because it is more pleasant for subjects and because it is more natural, mimicking the frequencies of speech sounds without taking on any particular phoneme cues which may be confounding.

5.3 Experiment 1: Masking in Templatic vs Concatenative Words in a Templatic Language

This experiment compares the relative ability to recover a word in the presence of masking noise in Hebrew depending on whether a root or non-root consonant is masked. Ideally root and non-root consonants would be masked in typical Hebrew words, using the same words across different participants. However, in Hebrew non-root consonants typically occur word-initially, where masking would make a word difficult to recover. Instead masking of a consonant in similar environments in non-root words is compared with root words, as had been done with experiments looking at visual lexical access (Velan and Frost 2011).

I predict that masking root sounds will make a word more difficult to recover than masking non-root sounds. Just as with letter transposition (e.g. Velan and Frost 2011), I predict that blocking root information will make a word more difficult to recover than blocking non-root information.

5.3.1 Methods

Subjects

Twenty four native Hebrew speakers (15 female and 9 male), age 20 to 59 participated in

the study. Subjects were volunteers from the Seattle and Los Angeles areas and were each offered \$10 as compensation for their time. All reported having no hearing problems.

Stimuli

Stimuli were all Hebrew words read off a list by the same male native Hebrew speaker, recorded using a Zoom H4n microphone and recorder. Stimuli consisted of an equal number of root based words (RB) and non-root based borrowings (NR) for the two conditions, totaling 48 words. Half the words (12 RB and 12 NR based) were recorded for the experimental condition. These words were balanced across conditions for frequency (RB: avg-3.5, range-1:14; NR avg-4.1, range-1:18) and number of syllables (3-tri-syllabic and 9-bi-syllabic of each). The remaining half (24 words, 12 each type) were unchanged and used as control for subject attentiveness and hearing.

In the experimental conditions a stop was deleted in the environment of a preceding consonant and following vowel (C-Stop-V). Deleted stops were controlled with the same number of each [b], [t], [p], and [g] deleted for the RN and NR type words. Similarly the preceding consonant was controlled with an equal number of each [r], other sonorants and obstruents for each word type. Following vowels were also nearly controlled with an equal number of each [a] and [i], and one different between types for [o] and [e]. It was not possible to control for exactly the same sounds with the same environment in words across types; however, as described, the number of each preceding, following and deleted sound type was nearly equal. See Table 5.1.

For each word in the experimental condition the stop and 90%¹ of the following vowel was deleted in Praat. The margin of 90% was chosen after piloting on native speakers to reach a threshold at which they did not reach a ceiling effect for the different conditions. The silence was then masked by brown noise which has similar wave patterns to speech without

¹Listeners have been shown to distinguish between vowels even with 10% of vowel information remaining (Parker and Diehl). Based on this and query of pilot listeners, enough vowel information is assumed to be present for the vowel not to be considered masked as well.

TABLE 5.1: Stimuli for Experiment 1: Masked Sounds and Environments

Preceding Consonant	Deleted Stop	Following Vowel
fricative (5)	[b] (2)	[a](5)
obstruents (4)	[p] (2)	[e] (3 R,4 NR)
sonorants (4)	[d] (3)	[o] (2 R, 1 NR)
	[t] (4)	[i] (2)
	[g] (1)	

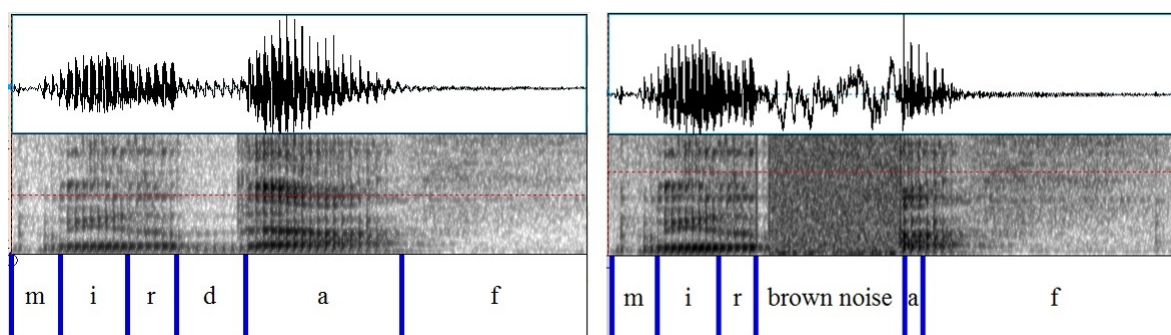


FIGURE 5.1: Masking: Before and After

the phoneme formant information at an equal amplitude to the remaining bordering sounds.

Procedure

The researcher met with participants in a quiet, mutually convenient place. All conversation between subject and researcher while administering the study (from the signing of consent form until the end of the task) took place in Hebrew. Each participant was asked to fill out a short demographic survey, querying age, gender, whether Hebrew is the participants' native language, whether or not the listener has any hearing problems etc.

Following the survey, participants were given a numbered, two-sided sheet of paper with 48 lines. Participants were instructed that stimuli would all be Hebrew words presented one

by one, but that some of the words would be interrupted by noise. They were asked to the best of their ability to say back the word that they had heard and then to write it down in the corresponding space. Participants were not limited in time to respond and response time was not measured, although the task took participants an average of 10 minutes to complete with most of the subjects taking an equivalent amount of time.

The words were presented in random order to each participant, using a random number generator to scramble the ordering. The first word presented was always a control word and was used to adjust the volume for the listener to a comfortable and easily audible setting. After each participant stated the word, the researcher also wrote the response on an identical sheet of paper to in order to verify responses and give two versions of handwriting for better identification. Participants were told that they could take a break at any point during the task, however none of them requested a break.

Analysis

All handwritten responses were coded in excel for each subject including whether or not subjects correctly identified each word.

The results of the identification of the experimental words were entered in a Logistic Mixed Effects Model using the lme4 library (Bates et al. 2013) in R (Pinheiro et al. 2009). Correctness of response was entered as the dependent variable, type of word (root-based or non-root based) as the independent variable and subject as a random variable.

5.3.2 Results

Controls

Subjects performed near ceiling for control words, with 4 out of 24 subjects misidentifying 1 out of 24 control words (96% accuracy) and the rest making no errors at all. The average accuracy of identification of control words across subject is 99.3%.

Root-Based vs Non-Root Based masked words

The log-likelihood of root based words being identified correctly is .4323 ($p < .01$). The

log-likelihood of non-root based words is .4506 greater than that ($p < .02$). Non-root based words with masking are 17% or 1.17 times more likely to be recovered than root-based ones.

Log-likelihood was converted to probability using the following formula: $\mathbf{logistic(a)} = \mathbf{1 / (1 + exp(-a))}$. The probability of a correct response given a root based word is $\mathbf{logistic(0.4323)} = 0.606422753$ and of a non-root based word is $\mathbf{logistic(0.8829)} = 0.707422812$. Dividing 0.707422812 by 0.606422753 gives the increase of likelihood that a word is correctly identified given that it is non-root based versus root-based.

5.3.3 Discussion and Conclusions

As predicted, masking of root phones made words harder to recover than masking of non-root phones. The results of this study suggest that as with visual lexical access, Semitic auditory lexical access is dependent on the processing of morphology. Root information in a root-based word appears to be more needed for access than non-root based information in a non-root based word. Masking a root sound only decreases the chances and does not completely inhibit lexical access as does transposing root letters in visual lexical access as shown in masked priming experiments (e.g. Velan and Frost 2011). However, in those experiments, the visual information was only presented for a very brief period of time (400ms), a condition that is not directly replicable in an auditory experiment. Thus the partial success of participants in auditory lexical access of words with masked root sounds may be attributed to the extra time available for the task.

Overall, these results indicate an important role of the root in auditory lexical access as well. Furthermore, this supports the proposal that has been suggested (e.g. by Frost 2012), that in Semitic languages root-based words are stored in the mental lexicon by the root. This proposal should be investigated further.

Finally, despite differences in the auditory and visual lexical access pathways that have been shown in the Background section, the results of this study show a similarity of the role of morphology in both of these pathways in lexical access in Hebrew. Whether this indicates a convergence of the pathways or parallel processes is something to be considered in further

research.

5.4 Experiment 2: Masking in Root vs Template (Preliminary results)

This experiment extends Experiment 1, investigating the importance of the root in auditory word recognition in Hebrew. While, the first experiment contrasts restoration effects for masking between concatenative borrowings and the typical templatic words, this experiment looks only at the typical templatic words. Masking occurs either over root sounds or template sounds.

In Experiment 1, the comparison is between two different types of words, a typical templatic word consisting of a stem and an affix and a concatenative borrowing. In Experiment 2, all words are of the typical templatic type allowing for a clear comparison between processing of the role of the root and the template in noun word recognition. I predict that nouns with template sounds masked will be easier to recover than those with masked root sounds given the importance of the root to visual word recognition as evidenced by the study in Chapter 4 as well as previous work on templatic languages (e.g. Velan and Frost 2009).

5.4.1 Methods

Subjects

Seventeen native Hebrew speakers participated in this study. Twelve of the subjects participated in this study as part of an ERP study and were tested in the U.S.; I will refer to these as group A. The remaining 5 did the study on its own and were tested in Israel; these are referred to as group B.

All participants reported normal hearing. They also all reported speaking in Hebrew on a daily basis regardless of country of residence.

Stimuli

Critical stimuli for this experiment are 60 nouns with initial sounds masked. For 30 of the words, the initial sound is the root and for 30 it is the template. Of these 10 begin with

the sound [t], 10 with the sound [m] and with the sound [h]. Critical stimuli are matched for following vowels, number of vowels and syllables and frequency (see Table 5.2). An additional 60 nouns with masked initial sounds that were not [m], [t] or [h] were used as fillers.

TABLE 5.2: Stimuli for Experiment 2: Masked Sounds and Environments

	Following Vowel	# Syllables	# Sounds	Frequency
Root	a=12, o=6, i=6, e=6	2.46 (2,3)	5.73 (5,7)	6.86 (1,25)
Template	a=13, o=6, i=5, e=6	2.40 (2,3)	5.85 (5,8)	6.55 (1,34)

Procedure For all participants, words were presented one by one with participants in control of rate of presentation. All participants were instructed to listen to words, some of which would have noise overlaying some of the word. They were told that each word is a real Hebrew word. The task was to identify the word and repeat back the word being spoken. Audio responses were recorded.

Participants in group A had EEG caps on and had brain responses recorded at the time of the experiment. The sounds were played from a speaker in a quiet testing room and responses were recorded from a standing microphone. These participants also participated in a separate unrelated experiment.

Those in Group B did not have ERP measurements being taken. Words were presented using the same circumaural headphones and the experiment took place in quiet locations. Responses were recorded using a portable microphone.

Analysis

All responses were transcribed in excel and coded for whether they matched the target word being spoken.

The results were then entered into Logistic Mixed Effects Model using the lme4 library (Bates et al. 2013) in R (Pinheiro et al. 2009). Correctness of response was entered as

the dependent variable, morpheme masked (root or template) as the independent variable and subject as a random variable. The model was compared to a null model and found significantly different.

5.4.2 Results

The log-likelihood of words with root letters masked being identified correctly is 0.7665. The log-likelihood of words with template letters masked is 0.3961 greater than that ($p < .01$). Template masked words are 12% or 1.12 times more likely to be recovered than root masked ones.

Log-likelihood was converted to probability using the following formula: $\text{logistic}(\mathbf{a}) = \mathbf{1} / (\mathbf{1} + \mathbf{exp}(-\mathbf{a}))$. The probability of a correct response given a masking of the root is $\text{logistic}(0.7665) = 0.682763288$ and given masking of a template is $\text{logistic}(1.1626) = 0.761804827$. Dividing 0.682763288 by 0.761804827 gives the increase of likelihood that a word is correctly identified given that the template is masked versus the root.

5.4.3 Discussion and Conclusions

Nouns with template sounds masked are easier to recover than those with root sounds masked. These preliminary results are in line with roots playing a bigger role in Hebrew noun recognition than templates. This mirrors the results of Chapter 4 (cite) looking at letter position flexibility in visual word recognition. In the visual study, nouns with transposed root letters didn't prime, while transposition of template letters did not inhibit reading.

The results of this experiment are preliminary given the different testing mechanisms employed for the subjects in Groups A and B. Further data will be gathered in the same mechanism as used for Group B to complete this study. There is no reason to expect that results from further testing would differ from these given that aside from the ERP set-up which is unlikely to affect morphological processing there is no significant difference in testing mechanism between the two groups.

5.5 General Discussion and Future Directions

Conclusions and Parallels to the Visual Domain

Together, these two experiments provide strong support for decomposition of templatic Hebrew nouns into their roots and templates during auditory word recognition. The results of Experiment 1 provide evidence of templatic and concatenative words being processed differently. Despite masking occurring in the same word position and environment, masked templatic words are harder to recover than concatenative ones. Experiment 2 then provides evidence that the root in particular plays a role in noun word recognition which is more vital than that of the template.

The role of morphology in noun recognition in the auditory study seems to directly parallel those of visual word recognition in Chapter 4. Root morphemes are sensitive to letter position in the visual domain and sensitive to masking in the auditory domain. Furthermore, the study by Velan and Frost (2011) looking at visual word recognition showed that concatenative words in Hebrew are letter position flexible in contrast to templatic words, paralleling the results of Experiment 1 in the auditory domain.

Further investigation is necessary to determine the full extent of parallels between morphological processing in the visual and auditory domains. The implications of these similarities, however, can already be considered. While the auditory and visual domains differ significantly as described Section 5.2.1, there seem to be clear arguments for some shared or at least equivalent representations not only at lexical, but also at morphological levels.

Future Directions

In a follow-up study, I plan to extend investigations in this study from nouns to verbs. This would allow for a further comparison between visual and auditory word recognition. It would not be possible to replicate Experiment 1 with verbs due to the lack of concatenative verb borrowings. Given that Hebrew verbs must fit one of seven templates any borrowings are quickly converted to be templatic by adapting the borrowing to be a root and inserting

it into one of the templates. The verb study will then parallel Experiment 2.

The results of the study in Chapter 4 revealed that while in nouns the root plays the primary role in templatic word recognition, while in verbs both the root and template play a role. If visual word recognition of verbs parallels that of auditory word recognition, I predict that masking in root versus the template would make a word equally hard to recover. Given the small number of templates, it is likely that just as in visual word recognition, these play an important role in auditory word recognition as well.

Chapter 6

READING WORDS WITH TEMPLATIC AND INFLECTIONAL COMPLEXITY: AN ERP STUDY

6.1 Chapter goals

In this Chapter I investigate reading templatic and concatenative words in Hebrew with and without inflectional affixation. In particular, the goal of the chapter is to look at decomposition of these words into their roots and templates, as well as into the stems and affixes during reading. Chapter 4 showed evidence of this in the visual domain and Chapter 5 in the auditory one. However, both of these experiments involve manipulation of the target stimuli with transpositions to the prime in the reading experiment and masking in the auditory one. Using the ERP paradigm it is possible to look at reading of unaltered words. Furthermore, as components have been shown to reflect decomposition of particular affix types in concatenative languages it is possible to draw parallels to processing in Hebrew. Finally, ERP allows for investigation into the time-course of these processes.

6.2 Introduction and Background

Neural correlates of reading complex words have been investigated in a number of mostly concatenative languages using ERP and MEG to investigate timing and processing, and fMRI and MEG for localization. The discussion here is on studies in which subjects read individual words without errors or priming, as this is the focus of the current study. Most of these studies have investigated either derivationally affixed, inflectionally affixed or compound words, and do not directly compare between these. Derivational and inflectional words have been shown to be recognized differently across languages in behavioral research (see Chapter 3); I will lay out some further differences that can be deduced from the results of the ERP and MEG

studies reported on here. The goal of this section is to summarize some of the findings from previous studies and lay out the research questions for the current study. I focus on studies using ERP and MEG as these are more comparable to the current ERP study. Both of these methods allow for measurements of electrical activity around the scalp and are sensitive to time-course; the results from these two methods are comparable.

6.2.1 Time-Line of Recognition of Complex Words

The processes of reading individual complex words has been broken down into two main steps (1)decomposition into stem and affix (e.g. ‘walker’→ ‘walk’ +‘er’) and (2) subsequent recombination (e.g. ‘walk’ + 1er’ → ‘walker’). This mechanism has been proposed for a variety of languages (e.g. Taft 2004[English]; Laine et al. 1994; Niemi et al. 1994 [Finnish]; see Chapter 3 for further discussion of reading models). Through mechanisms such as masked priming and ERP/MEG studies these processes can be assigned rough time windows. Orthographic recognition involved in the decomposition step is observed to start around 100 ms after presentation (Sereno et al. 1998). Semantic integration which is tied to the recombination step has been shown to occur later at the N400 component, peaking around 400 ms after word presentation (Kutas et al. 1980). Thus, when comparing complex words with monomorphemic ones, differences observed in the earlier time-windows can interpreted as processing costs of decomposition, while those at later time-windows can be interpreted as processing costs of recombination.

6.2.2 Previous ERP and MEG Work

To date there have been several ERP and MEG studies comparing reading of complex and monomorphemic words in concatenative languages. One goal of these has been to investigate processing of complex words, showing evidence of decomposition. Another is determining the point during recognition at which costs for reading different types of complex words are

incurred (i.e. during recombination or decomposition).¹ These studies have investigated reading words with either derivational or inflectional affixes or at compounds; few directly compared the affix types. In this section, I summarize the studies separately by complexity type and then and compare between them. The results are also summarized in Table 6.1.

Derivational

I report on three studies investigating reading words with derivational affixation. All of the effects observed for derivational words occurred in the early time-windows. This is in line with a cost of processing derived words being incurred at the decomposition stage.

Zweig and Pylkkänen (2009) compared reading affixed and simple words in a lexical decision task with MEG in English. In the first experiment, bi-morphemic words had the suffix -er and in the second the prefix re-. The words in the first experiment were all nouns, while the ones in the second experiment were verbs. For both types of derivational affixes, Zweig and Pylkkänen (2009) found an effect in the 140-200 ms window (which they classified as M170) with a higher amplitude peak for bi-morphemic than mono-morphemic words.² These early effects are at the time-windows in which decomposition is thought to occur. A greater amplitude peak for derivational words manifested in the early time-window may be associated with a greater processing load at decomposition.

In a further study, Solomyak and Marantz (2010) investigated a larger subset of English derivational affixes, looking at both bound and free stems, as well as frequency effects. They found a significant effect of morphological affix frequency in the left hemisphere in the M170 time-window across stem types. Morphological frequency here refers to the frequency with which those final letters (e.g. *able* in *sealable*) appear as an affix as opposed to just as

¹A number of these studies have also looked at whether there is a semantic component to decomposition or whether initial stages of recognition are purely orthographic. This was done by comparing pseudo-complex words, i.e. words that have orthographic features matching complex words (e.g. *corner*) with affixed words (e.g. *worker*) and monomorphemic words (e.g. *strike*) in addition to comparing affixed and un-affixed pseudowords. This question is outside of the scope of this chapter and results relating to this are omitted from the discussion here; see Chapter 3 for further discussion of this question.

²This effect was only significant in the right hemisphere.

word endings (e.g. *able* in *table*). As Zweig and Pylkkänen (2009), Solomyak and Marantz (2010) observed differences in peak amplitude at the early window were associated with decomposition.

Lavric et al. (2012) conducted a similar experiment with a lexical decision task comparing reading of English bi-morphemic and mono-morphemic words using EEG. Stimuli in the bi-morphemic condition were nouns and adjectives composed with a variety of suffixes. The words in this study were both nouns and adjectives. They observed a difference in amplitude in the 190-220 ms time window between mono-morphemic and bi-morphemic sites at central and posterior electrode sites. The timing of the effect in this study is analogous to the MEG studies and can also be interpreted as a manifestation of a decomposition cost.

Inflectional

In contrast to derivational words, the cost of recognizing inflectional words manifests itself later at the recombination stage. I report on three studies investigating inflectional complexity; all are conducted with Finnish nouns.

Lehtonen et al. (2007) investigated reading of individual inflected Finnish words using an ERP lexical decision task. Stimuli were mono-morphemic words and inflected bi-morphemic words that had case marking affixes. Inflected words differed from monomorphemic ones in the 550-650 ms time-window. This is the time-window at which recombination is thought to occur; a greater amplitude effect likely reflects a processing cost of recombination.

Vartiainen et al. (2009) performed a similar experiment with inflectionally affixed and mono-morphemic words in Finnish using MEG. In contrast to some of the other studies here, the task was a passive reading task in which there was no decision action required following any of the target stimuli. The stimuli in this experiment are bi-morphemic words inflected for case and mono-morphemic words. Bi-morphemic words have higher amplitude peaks in the 330-500 ms window in left temporal and parietal regions (N400). Just as with the Leinonen et al. (2009) study, the time-window at which costs manifested in this study are the time of recombination.

Leinonen et al. (2009) compared Finnish inflectional and mono-morphemic and words using ERP in both the visual and auditory domain. The effect morphological complexity effect was found for both visual and auditory word recognition of case inflected vs mono-morphemic words. The visual effect was significant in the 400-500 ms time-window (N400), also in the time-window associated with recombination.

Compounds

Two studies have looked at reading individual compound (vs. monomorphemic) words without errors or priming. The focus of these studies are on lexicalized vs. novel compounds as well as on headedness of the compound. As such, only some of the results are relevant to the current study; I will focus on these here. In a lexical decision study of reading individual words, El Yagoubi et al. (2008) compared monomorphemic words and compounds in Italian and Fiorentino et al. (2014) in English. Both found that compound words had more negative peaks in the 270-370 ms window (275-400 for Fiorentino et al. 2014) as compared to monomorphemic words. In the Fiorentino et al. (2014) study the compounds in the comparison were all lexicalized, while in the El Yagoubi et al. (2008) study, lexicalized and novel compounds are combined. The important observation here is that effects at which compounds and monomorphemic words differed were observed in the same time-window for both studies.

It is difficult to directly compare these results with those looking at derivational and inflectionally complexity since the time-windows in these studies are fairly large compared to the other studies looking at complex words and overlap both the early time windows around 200-300 range and the N400 time-window in the 350-500 range. Furthermore, the authors do not report on every comparison with lexicalized compounds and monomorphemic words (i.e. excluding novel compounds) and there may be additional effects not reported on here. Thus, no clear conclusion can be drawn as to the point at which decomposition costs for compounds are incurred. Just as with the other types of concatenative complexity, however, there are clear and consistent differences observed between compounds and monomorphemic

words, which are in line with a decomposition approach into stems.

TABLE 6.1: Summary of ERP and MEG Studies Investigating Derivational Components

<i>Derivational</i>			
Authors	Language	Method	Effect/Window
Zweig and Pykkänen (2009)	English	MEG	M170 (140-200 ms)
Solomyak and Marantz (2010)	English	MEG	M170 (n/a)
Lavric et al. (2012)	English	ERP	N190 (190-220 ms)
<i>Inflectional</i>			
Authors	Language	Method	Effect
Lehtonen et al. (2007)	Finnish	ERP	N400 (550-650 ms)
Vartiainen et al. (2009)	Finnish	ERP	N400 (330-500 ms)
Leinonen et al. (2009)	Finnish	ERP	N400 (400-500 ms)
<i>Compounds</i>			
Authors	Language	Method	Effect
El Yagoubi et al. (2008)	Italian	ERP	(270-370 ms)
Fiorentino et al. (2014) ³	English	ERP	(275-400 ms)

6.2.3 Summary of Observations

All three types of concatenative complex words: inflectionally affixed, derivationally affixed and compounds, differ from monomorphemic words, which is in line with decomposition of these words into their constituent morphemes. The results of the studies looking at compound words remain inconclusive in terms of the timing at which cost is incurred. Inflectional

³The compounds in this comparison include both lexicalized and novel ones and therefore may not be comparable to the other studies described here. However, it is important to note that the effect here is in the same time-window as the effect found in English by Fiorentino et al. (2014) , where compounds are all lexicalized.

and derivational affixes do appear to differ consistently in terms of timing of costs incurred. The cost for recognizing derivational words manifests in the early time-window associated with decomposition, while inflectional costs manifests around the N400 time-window associated with recombination. Properties of derivational and inflectional affixes may account for these differences observed between them.

Derivational affixes vary in productivity, which may make them harder to detect and parse at the decomposition stage. That is, derivational affixes only apply to certain words or sub-classes of words, in contrast to inflectional affixes which typically can be applied widely. On the other hand, derivational affixes are typically semantically transparent and typically do not need to match the stem grammatically (i.e. for person, gender, etc.). This may account for the fact that cost was not manifested at the decomposition stage.

Inflectional affixes, on the other hand are typically highly productive. For instance, case marking and pluralization can be applied to a large number of nouns. This may make them easier to detect at the decomposition stage, resulting in no cost manifested. Unlike derivational affixes however, inflectional affixes have a less direct relationship to meaning and often include some type of grammatical agreement with the stem. These may be the reason for the observed processing costs at the recombination stage.

One limitation of the current work is that the inflectional studies have all been on English and the derivational ones all on Finnish. There are studies looking at other languages, which have priming as a mechanism, however the timing of priming and reading of individual words is hard to compare. That is, priming effects are observed around the N400, regardless of decomposition type and as such do not provide insight into timing of recognition costs for complex words.

6.2.4 Current Study: Research Questions and Predictions

While ERP and MEG studies on reading individual complex words have been conducted in concatenative languages, no analogous study has been conducted in a templatic language. The goal of this study is to investigate both affixational (inflectional) and templatic com-

plexity in Hebrew word recognition, using the ERP paradigm.

As with previous studies with concatenative languages investigating inflectional affixation (e.g. Leinonen et al. 2009), inflectionally affixed words were compared with unaffixed ones. In contrast to concatenative languages, however, templatic stems are themselves complex consisting of a root and template. Thus, in addition to using typical templatic words, concatenative borrowings are also included in this study. As discussed in Chapter 3, concatenative words include high frequency words (such as the word for ‘table’) and some have been integrated into the language for thousands of years. These concatenative words appear to be recognized just as concatenative words in other languages, different from the typical templatic words. For instance, Velan and Frost (2011) showed that concatenative nouns in Hebrew are letter position flexible and that these words with transposed letters do prime, unlike templatic words. This suggests that concatenative words are not decomposed like templatic ones. The results of Chapter 5 provide further evidence of concatenative words being processed holistically, extending to the auditory domain where concatenative words with sounds masked are easier to recover than templatic ones. In investigating affixational complexity, both concatenative and templatic words are used and are analyzed separately. In order to investigate templatic complexity, concatenative nouns are compared to templatic ones.

The specific questions of interest in this study are the following: (1) Do Hebrew readers decompose inflectionally affixed words just as readers of concatenative languages do? If so, does the cost for decomposition present itself at a similar time frame around 400ms after word presentation (N400)? and (2) Is there evidence of readers decomposing templatic words (in contrast to concatenative borrowings)? If so, does the cost manifest itself as a similar difference in amplitude as that observed for concatenative readers of either derivationally complex words ($\tilde{1}90$ ms) or inflectionally complex words ($\tilde{4}00$ ms).

Since inflectional affixation is comparable in Hebrew to that of concatenative languages with an affix attaching to a stem, Hebrew readers likely decompose inflectionally affixed words into stems and affixes just as concatenative readers do. I predicted that inflectional

affix decomposition incurs a cost at the recombination time-window (N400), just as with concatenative languages. I did not anticipate that concatenative and templatic words would differ in this regard.

Given the evidence for decomposition of templatic words in roots and templates (e.g. priming by semantically unrelated words sharing a root Deutsch et al. 1998), I predicted that concatenative and templatic words would differ. I had no specific time-window prediction for these whether these costs would manifest at earlier or later time-windows as this type of complexity has not been previously investigated. I had two possible predictions for the direction of the cost. If the default mechanism of Hebrew is decomposition (and subsequent recombination) of the stem into a root and template, then reading concatenative borrowings would have the higher processing cost, as reflected in greater peak amplitudes. Alternatively, it is possible that decomposition and recombination is more costly regardless of the prevalence of templatic word structure.

Initially, I had also set-out to look at individual differences in responses based on reading proficiency. A number of studies have found effects of reading skills and both Early and N400 reading responses (e.g. Perfetti et al. 2008; Korinth et al. 2013). However, given that all subjects performed at ceiling or nearly at ceiling at the reading proficiency task, this comparison was not possible.

6.3 Methods

6.3.1 Participants

Participants were 21 native Hebrew speakers aged 19 to 54 (average 36 years) currently residing in the Seattle, Washington area. 14 males and 7 females participated in this study. All participants filled out a detailed language background questionnaire. Questions included gender, age, history of vision or hearing problems, age of acquisition of any other languages including English, years spent in each country including Israel and the U.S. and self-assessed proficiency in Hebrew and any other languages. They also were asked to estimate percentage

of time spent on various activities in Hebrew versus any other languages as well as to estimate time spent doing each of these activities in Hebrew. Participants filled out a questionnaire on familial sinistrality and completed a Hebrew proficiency test.

Length of stay in the United States varied by participant. On average they lived in the U.S. 7 years, ranging from 0 to 16. All participants self-rated Hebrew proficiency in Reading, Writing, Speaking and Understanding 7 out of 7 (native speaker). 6.2 summarizes percentage of time as well as hours spent weekly by participants speaking, reading, writing and watching (e.g. television) in Hebrew. All participants engaged in each of these activities in Hebrew on a daily basis.

Participants additionally performed a reading test to assess Hebrew reading proficiency. The questions from the proficiency exam are taken with permission from the official YAEL Hebrew Proficiency Test used to assess Hebrew reading proficiency for Israeli Universities. The test consisted of a total of 30 questions made up of: Sentence Completion, Sentence Restatement and Reading Comprehension. Most participants performed at ceiling. The average score on the test was 29 out of 30 (97%), with a range of 24 to 30. Participants were not limited in time; they took an average of 14.7 minutes to complete the test.

TABLE 6.2: Participants' Use of Hebrew on Average

	Percentage Time	Hours Spent
Speaking	52%	34
Reading	41%	18
Writing	37%	13
Watching	36%	11

Average percent of time participants spend doing each activity in Hebrew (versus English) and average time spent doing each activity in Hebrew weekly

6.3.2 Materials

Stimuli consisted of 152 words and 152 corresponding pseudowords. The words were split between four conditions in a two by two cross design as illustrated in 6.3. Seventy six of the words were concatenative (borrowings into Hebrew) and 76 were templatic (native words consisting of a root and template). Of each of these, half (38) were affixed and half are not. Thus, there were 38 words in each condition. Affixes used in this experiment were all inflectional. They were the masculine and feminine plural suffixes -‘im’ and -‘ot’ respectively, as well as the definite marker prefix ‘h’-.

The pseudowords were created by substituting a letter in a real word and were matched to the real words. Seventy six of the pseudowords were created from concatenative words, substituting one of the letters and 76 using templatic words substituting one of the root letters. For each of these, half were affixed using the same real affixes as the words and half were un-affixed.

Stimuli were balanced between two lists. The words and pseudowords that were affixed in List 1 were un-affixed in List 2 and vice versa. For each list there were two pseudo-randomly ordered versions for a total of 4 lists. Lists were rotated between subjects.

TABLE 6.3: Stimuli: Examples for Each Condition

	-Affix	+Affix
Concatenative	Sulxan <i>table</i>	Sulxan-ot <i>table +pl</i>
Templatic	MiKTaV <i>postal letter</i>	MiKTaV-im <i>letter-pl</i>

6.3.3 Procedure

Participants took part in a single session lasting between 1.5 and 2.5 hours.⁴ At the start of the session participants were asked to complete language and sinistrality questionnaires followed by a proficiency test administered by laptop computer.

Participants were seated in a comfortable armchair for the duration of ERP recordings. They were instructed to read words and decide whether the words were real Hebrew words or not by making a selection via button press; real words were identified with either left or right hand buttons, pseudo-randomly assigned to subjects. Participants were encouraged to relax and were asked to minimize any movements including eye-movements and blinks while words appeared on the screen.

Each trial consisted of a blank screen for 300 ms, followed by a fixation cross for 1 sec and then stimulus presentation; words remained on the screen until participants' button press. There was a 1 sec ISI following the button press.

6.3.4 Data Acquisition and Analysis

Behavioral Analysis

Reaction times and error rates were analyzed using separate repeated measures ANOVAs. Three within subjects variables were included: *lexicality* (word, pseudoword), *type* (templatic, concatenative) and *affixation* (affixed, unaffixed).

ERP Acquisition and Analysis

Continuous EEG was recorded from 30 active tin electrode sites in an elastic cap according to the 10-20 system (Jasper (1958)). Reference was established with an electrode at the left mastoid. Eye blinks were monitored with two electrodes, one positioned to the right of the right eye and one below the left eye. An electrode was also placed at the right mastoid to

⁴The time of the session depended on whether participants participated in a second separate experiment. The second experiment always took place following this one.

measure any experimental effects which could be observed at the mastoid site. There were no such effects observed. A bandpass filter of 0.01–40 Hz (-3db cutoff) by an SAI bioamplifier system was used to amplify the EEG signal. Offline filtering of ERP was done to below 30 Hz. Scalp electrode impedances were held below 5 k Ω while impedances at the eye electrodes and mastoids were held below 3 k Ω and 10 k Ω respectively.

A sampling frequency of 200 Hz was used for continuous online digital-to-analog conversion of EEG and stimulus codes. ERP's were time-locked to the onset of words and were averaged offline per condition per participant at each electrode site. Trials with eye blinks, movements or other artifacts were excluded. All other trials were included in the ERP averages.

A repeated-measures ANOVA with two levels of complexity was used to calculate differences between conditions. The levels were either affixation (affixed versus un-affixed) or word type (concatenative versus templatic) depending on the comparison.

For each condition, the effect was calculated separately at the midline (Fz, Cz, Pz), lateral electrodes (left hemisphere: F7, FC5, T7, CP5, P7; right hemisphere: F8, FC6, T8, CP6, P8), medial-lateral electrodes (left hemisphere: Fp1, F3, FC1, C3, CP1, P3, O1; right hemisphere: Fp2, F4, FC2, C4, CP2, P4, O2), and at 9 central sites (left hemisphere: F3, C3, P3; midline: Fz, Cz, Pz; right hemisphere: F4, C4, P4), where morphological complexity effects were reported by Leinonen et al. (2009).

ANOVAs on midline electrodes included electrode as an additional within-subjects factor (three levels), ANOVAs on lateral electrodes included hemisphere (two levels) and electrode pair (five levels), ANOVAs on medial-lateral electrodes included hemisphere (two levels) and electrode pair (seven levels) as additional within-subjects factors, and ANOVAs over central electrodes included hemisphere (two levels) and electrode pair (three levels) as additional within-subjects factors. ERPs were averaged and quantified within particular time windows.

Time windows of interest were selected based on observed differences and in line with previous studies. Early time-windows at 80-120 ms, 190-220 ms and 200-300 ms were selected. In addition later time-windows were selected at 350-450 ms, 300-500 ms (N400) and at 600-

800 ms (P600). All time-windows were relative to a 100 ms prestimulus baseline.

6.4 Results

6.4.1 Behavioral Results

Reaction Time

Mean reaction times for word and pseudoword conditions are reported in Table 6.4. There was a significant main effect for *lexicality* ($F(1,20)=20.48$, $p=.0002$), with longer reaction times for pseudowords than words. Across words and pseudowords, *affixation* was found to be a significant predictor of reaction time ($F(1,20)=20.94$, $p=.0002$) with longer reaction times for affixed than unaffixed. The main effect of *type* (concatenative vs. templatic) was not significant. There was no significant interaction between any of the factors.

Error Rate

Average error rates by condition are shown in Table 6.4. There was no significant main effect for *lexicality* for error rate. There was a significant overall main effect for affixation ($F(1,20)=7.24$, $p=.01$). *Affixation* interacted significantly with *lexicality* ($F(1,20)=5.69$, $p=.03$), as reflected by greater error rates for the affixed condition in words and smaller error rates for the affixed condition in pseudowords. There was also a significant interaction with *lexicality* and *type* ($F(1,20)=21.70$, $p=.0002$) and a three-way significant interaction between *lexicality*, *type* and *affixation* ($F(1,20)=8.77$, $p=.008$).

TABLE 6.4: Summary of Behavioral Results

Stimulus Type	Reaction Time (ms)	Error Rate
Concatenative UnAffixed	790 (297)	4.39 (3.36)
Concatenative Affixed	876 (411)	8.77 (4.58)
Templatic UnAffixed	802 (313)	3.01 (3.15)
Templatic Affixed	876 (461)	4.01 (3.18)
Concatenative UnAffixed Pseudoword	952 (395)	3.38 (5.14)
Concatenative Affixed Pseudoword	1038 (510)	2.01 (4.07)
Templatic UnAffixed Pseudoword	992 (480)	5.39 (10.14)
Templatic Affixed Pseudoword	1060 (516)	6.64 (7.33)

6.4.2 Concatenative: Affixed vs Unaffixed

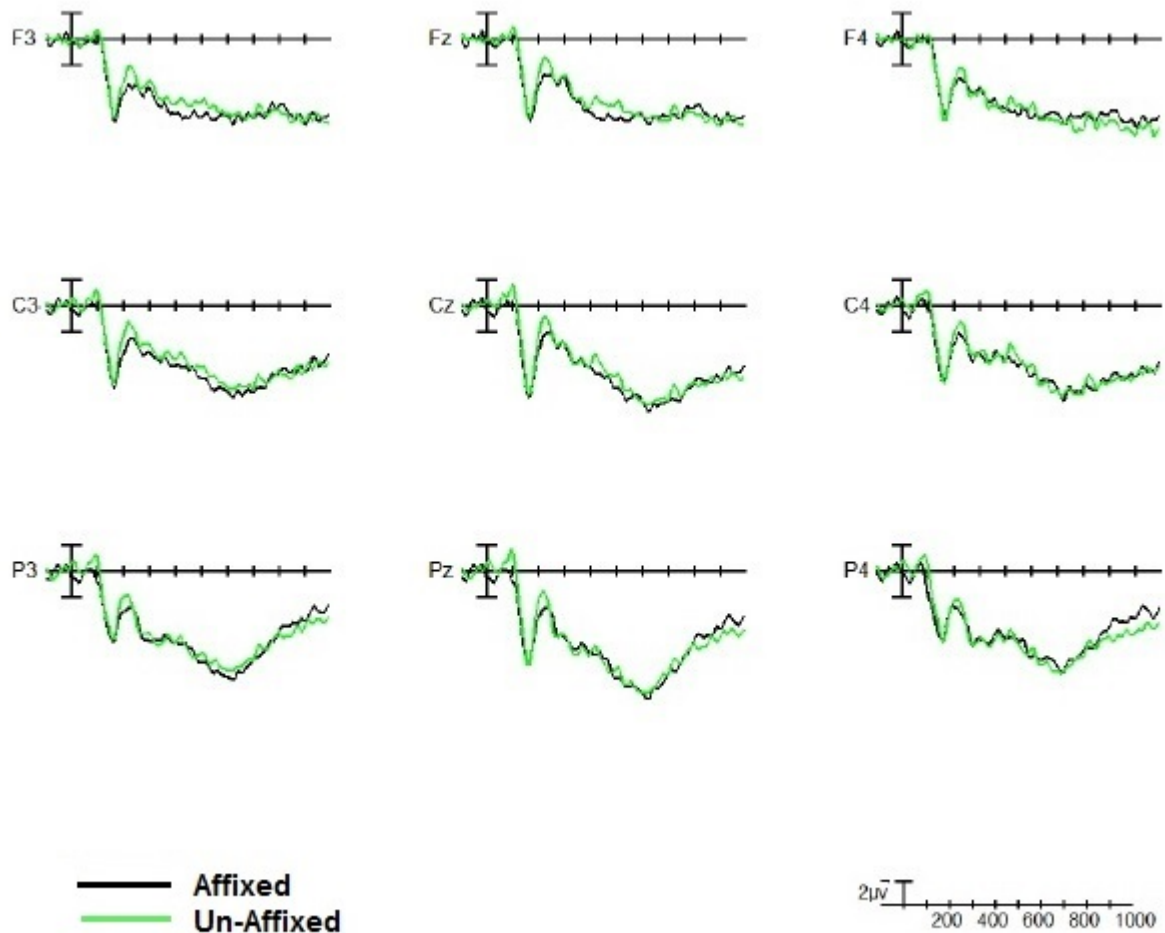


FIGURE 6.1: Concatenative: Affixed vs Un-affixed

Visually, the two wave-forms are nearly overlapping. There is a slight difference at the central electrodes around 200 ms, but this is not significant. No significant effects were observed at any time-window of interest at any of the measured electrode sites.

6.4.3 Templatic: Affixed vs Unaffixed

An effect of affixation for templatic words was observed in the N400 time-windows. Inflectionally affixed templatic words have a greater amplitude N400 at the 300-500 ms time window at the midline (midline: $F(1,20)=5.190$, $p=.034$). This effect is also significant in the 350-450 time window at midline, medial-lateral and central sites (midline: $F(1,20) = 8.852$, $p=.007$; medial-lateral: $F(1,20)=6.149$, $p=.022$; central: $F(1,20)=6.770$, $p=.017$).

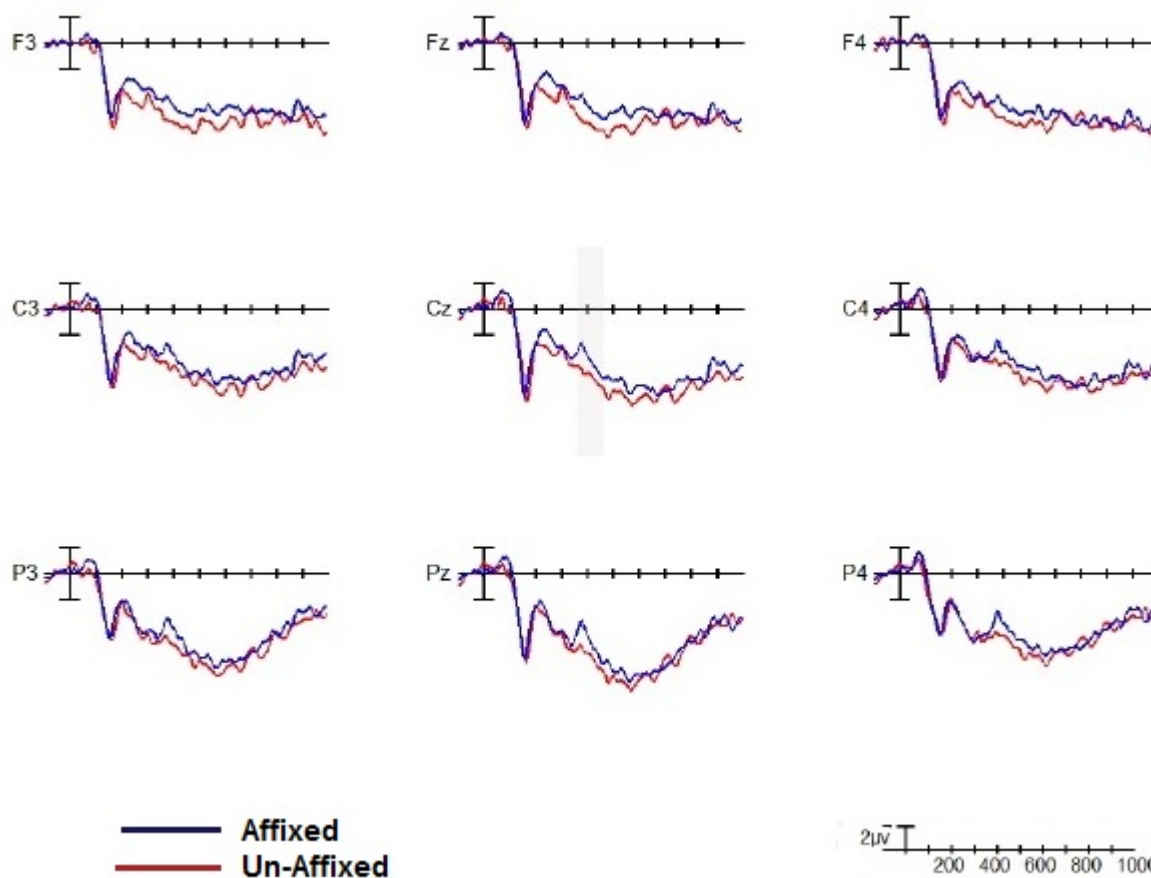


FIGURE 6.2: Templatic: Affixed vs Un-affixed. (Time-window with significant effect is shaded on the CZ electrode)

6.4.4 *Templatic vs Concatenative*

Visually, both an early effect 200ms and later N400 effect is observed. Only the early effect is significant. Additionally an early effect in the 80-120 ms time window is significant, though very slight as can be observed in Figure 6.3. Concatenative words have a higher amplitude peak at 80-120 ms at all investigated electrode sites (midline: $F(1,20)=6.789$, $p=.017$; medial-lateral: $F(1,20)=5.506$, $p=.029$; central: $F(1,20)=5.705$, $p=.026$). This effect is observed in the 200-300ms window as well (midline: $F(1,20)=4.859$, $p=.039$; medial-lateral: $F(1,20)=4.393$, $p=.049$; central: $F(1,20)=4.633$, $p=.044$).

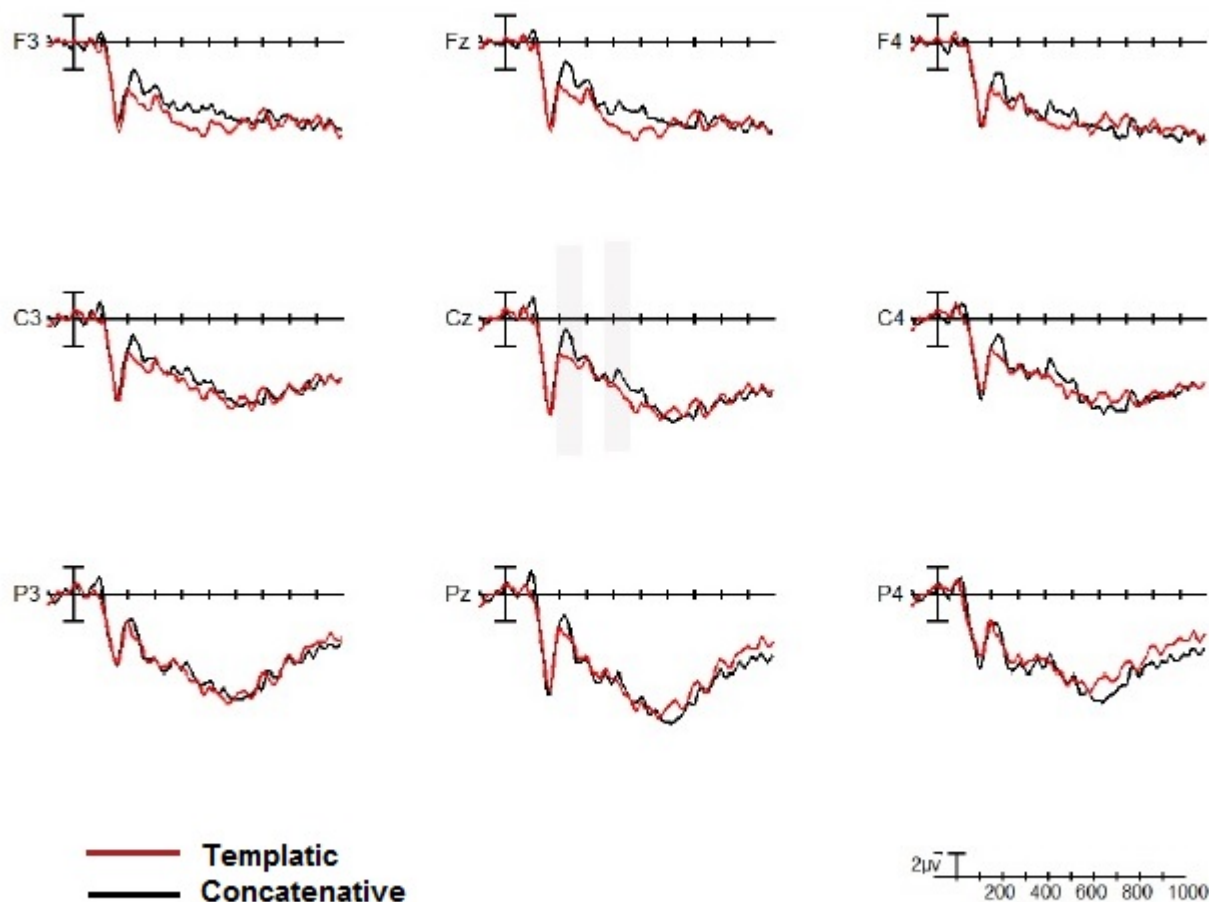


FIGURE 6.3: Concatenative vs Templatic (Time-windows with significant effect are shaded on the CZ electrode)

6.4.5 Summary

In summary, effects were observed for inflectional affixation in templatic, but not concatenative words. These manifested as an N400 with a greater amplitude peak for affixed than un-affixed words. There was also an effect for templatic vs concatenative words with a

higher amplitude peak for concatenative than templatic at two early windows: the 80-120 and 200-300 time windows.

No significant effects were found at lateral electrodes in any of the conditions. Additionally, no significant effects were observed in the 600-800 ms (P600) time window for any of the conditions.

6.5 Discussion and Further Research

Overall the results point to a difference in processing of concatenative borrowings and templatic words during reading. They are also in line with a decomposition of stems and inflected affixes. In this section, I discuss the different results separately and relate them to a more general model, as well as proposing further research directions.

6.5.1 Behavioral and ERP Findings

Behavioral

A significant processing cost was revealed in both reaction times and error rates for inflectional affixation. Longer reaction times and greater error rates were observed for affixed real words, regardless of type (concatenative vs. templatic). This is in line with a decomposition approach into stems and affixes for all inflectionally affixed words. Longer reaction times were also observed for affixed pseudo-words as compared with unaffixed ones, suggesting that at least initial decomposition processes are not semantic. The effect of affixation on error rates for words and pseudowords differed with increased error rates for affixed words and decreased error rates for affixed pseudowords.

ERP: Concatenative Affixation

Inflected concatenative words did not differ significantly from monomorphemic ones at any of the time-windows for any of the electrode site groups. This is in contrast to the prediction that inflectional decomposition costs would manifest in greater amplitude in the N400 time-window as in concatenative languages (e.g. Lehtonen et al. 2011). However, it is

not possible to conclude from this finding alone whether inflected concatenative words are stored holistically or they are in fact decomposed during reading just as in concatenative languages. In fact, the behavioral results of longer reaction times and greater error rates for affixed words do seem to reflect decomposition costs. The lack of difference in the ERP wave-forms may then be due to the fact that concatenative words are themselves not typical in the language, resulting in processing costs that may mask inflectional processing costs.

ERP: Templatic Affixation

For templatic words, an effect of affixation was observed in the N400 time-window. Inflected templatic words have a higher amplitude peak than uninflected templatic words in the 350-450 ms time-window (N400). As predicted, inflected templatic words manifested costs similar to inflected words in concatenative languages. This is consistent with inflected words being decomposed into stems and affixes during word recognition. Just as with concatenative languages, the cost for this decomposition occurs around the N400 time-window. This is in line with inflectional costs being manifested at recombination.

ERP: Templatic vs. Concatenative

Templatic and concatenative words differ in early time windows associated with decomposition (200-300 ms). Concatenative words have a greater amplitude peak than templatic ones. This is in line with differing recognition mechanisms for templatic and concatenative words. Namely, templatic words are decomposed into stems and affixes, while concatenative ones are accessed as whole word forms. The greater amplitude for concatenative than templatic words suggests that there is a higher cost for processing the former than the latter. This suggests that the default (and less costly) mechanism in Hebrew as a templatic language is decomposition of (noun) stems into roots and templates.

6.5.2 *Implications for Reading Models*

The results of the comparisons in this study provide evidence that both templatic and affixational morphology play a role in Hebrew word recognition. Inflectionally affixed (templatic) words are decomposed into stems and affixes. Concatenative words have greater processing costs than templatic ones, indicating that decomposition of the stem into root and template is the default mechanism. I lay out a possible approach to account for these findings. This approach is recognition model agnostic and could be applied to any compatible recognition model.

The observed differences between concatenative and templatic words in this study and previous work such as Velan and Frost (2011) suggest that concatenative words are accessed as whole words, while templatic ones are accessed through the root and template. I propose that the lexicon for Hebrew, then, includes roots, templates and whole-stem representations.

5

While templatic words can be accessed through roots and templates, concatenative words only have whole-stem representations. The default (and less costly) path to recognition in Hebrew is through root and template, rather than whole-word recognition. Given that it is not always possible to tell that words are concatenative initially, all words likely undergo a search for roots and templates. The processing cost for recognizing concatenative words may also stem from this unsuccessful search. It is important to note that while the difference in peak amplitude in ERP response does reflect a greater processing cost, the behavioral results reflect no difference in reaction time. Thus recognition of concatenative and templatic words must be equally fast and differ in cost alone.

As with concatenative languages, Hebrew readers appear to decompose inflectionally affixed words into stems and affixes. Thus, the Hebrew lexicon includes affixes separate from

⁵Whole-stem representations may only be available for concatenative words or for both concatenative and templatic words. If whole-stem representations of templatic words are available as well, it is necessary to account for the difference in letter flexibility observed by Velan and Frost (2011) where concatenative words with transposed letters do prime and templatic ones do not.

their stems. The results of this study can be interpreted in terms of a full decomposition approach such as Taft (2004) or a dual route approach such as Paap and Noel 1991. That is, there may be representations of affixed stems in addition to bare stems and affixes. However, both the behavioral and ERP results suggest that a decomposition route is available and used at least for some inflectional affixes.

6.5.3 *Further Research*

In concatenative languages decomposition effects have been shown using ERP for auditory word recognition, just as with visual word recognition (e.g. Leinonen et al. 2009 [Finnish], Leminen et al. 2011 [Finnish], Whiting et al. 2013 [English]), however little has been done with templatic languages. I would like to extend this work to the auditory domain. A replication of this experiment with auditory stimuli would allow for comparison between auditory and visual word recognition in Hebrew as a templatic language. It is also a way to investigate word recognition in a templatic language without the confound of a different orthographic system.⁶ This ERP method has advantages over the phonemic restoration method used in the study in Chapter 5 in that no manipulation of the auditory signal is needed.

In addition, the results of Chapter 4 suggest there is a difference in processing verbs versus nouns in Hebrew. Nouns with transposed root letters do not prime, while verbs do. This suggests that the role of the root is more important to noun recognition than verb recognition. As a follow-up, I plan to extend this study to look at verb recognition. The challenge with looking at verbs is that borrowed verbs are necessarily integrated into the template system. As such, there are no concatenative verbs in the language, preventing a direct comparison to the current noun study. It would be possible to manipulate frequency of the root and template while keeping word frequency steady and vice versa however. Given that ERP components such as the N400 are sensitive to frequency effects (e.g. Dambacher

⁶The difference in orthographic system referred to here is the omission of most vowels in Hebrew and Arabic in writing unlike in other alphabet orthographies such in English or Basque.

et al. 2006, Vartiainen et al. 2009), this type of manipulation would allow for exploration of verb reading mechanisms and specifically of decomposition effects. That is, if effects are found for surface and component frequency, it would provide evidence for decomposition. Given the limited number of verb templates, it is possible to compare differences in processing different templates. Recent work by Farhy et al. (2017) suggests such differences present. Furthermore, this would allow for further investigation of the role of the root versus template by manipulating frequency for each of these components individually and comparing the effects. This manipulation can also be done with nouns to draw a further comparison between verb and noun word recognition. In terms of inflectional affixation, I would predict similar results for verbs and nouns since these effects reflect stem and affix decomposition rather than decomposition into a root and template.

Chapter 7

READING A TEMPLATIC LANGUAGE AS A SECOND LANGUAGE

7.1 Chapter goals

In chapters 4-6, I have focused on native word recognition of Hebrew as a Semitic language. The results of these experiments confirmed the role of templatic morphology in native Hebrew speaker word recognition. The goal of this chapter is to investigate whether this mechanism is acquired by native speakers of a concatenative language, for whom Hebrew is a second language. Using the same masked paradigm as was used in Chapter 4, this chapter investigates whether second language speakers of Hebrew have the same reading mechanism as native speakers or whether there is transfer from their first language. In addition, I investigated whether acquisition correlated with age of acquisition or arrival.

7.2 Introduction and Background

Results from Chapter 4 and from previous studies (e.g. Velan and Frost 2009, Perea et al. 2010) show that readers of templatic languages are more sensitive to letter position than concatenative readers, particularly with respect to nouns. These suggest different reading mechanisms for reading in concatenative and templatic languages. Furthermore, Velan and Frost (2011) have shown that letter position is flexible in Hebrew for concatenative noun borrowings, suggesting that more than one mechanism is employed by native Hebrew readers. However, little is known about the reading mechanisms second language (L2) learners of a templatic language such as Hebrew, whose first language (L1) is concatenative. Frost et al. (2013) showed that second language reading proficiency in Hebrew, for native English speakers, is correlated with the ability to predict transitional probabilities in visual shapes.

The actual reading mechanisms employed have not yet been investigated, however. In this experiment, I investigate this question by having learners do the same transposed letter experiments as native Hebrew speakers did in Chapter 4.

7.2.1 Age of Acquisition and Reading Proficiency

In second language research, one of the most commonly investigated questions is whether late acquirers can master a second language. This line of inquiry is centered around a critical period for second language acquisition after which native-like acquisition is no less possible. In this study, I investigate whether age of acquisition or arrival plays a role in acquisition of the reading mechanism in the L2.

The critical period theory comes from biology and was developed in the late 19th century. Its application to language and first language acquisition emerged in the late 20th century with Penfield (1959) and Lenneberg (1967). For first language acquisition a critical period refers to the fact that if a person is not exposed to language (any language) by a certain age, the person will never be capable of fully learning a language (Lenneberg, 1967; Penfield, 1959). Evidence in support of this comes from deaf individuals who were only taught a language late in life (e.g. Morgan and Kegl 2006 looking at late learners of Nicaraguan sign language as an L1).

For an L2, there are two main approaches to this question, (1) there is no biological critical period, rather many factors including age of acquisition play into the degree of mastery (e.g. Muñoz and Singleton 2011) and (2) there are particular cut-offs for different areas of acquisition: pronunciation, morpho-syntax and lexis (e.g. Granena and Long 2013). Arguments for or against a critical period can be made from a few different perspectives. Generally arguments for a critical period are made by measuring second language learners' success in acquiring a second language on the level of a native speaker. Experimentally, evidence in favor of a critical period would show an age of acquisition after which proficiency tends to decrease as well as an age after which native-like attainment is no-longer possible. In contrast, arguments against a critical period would show native-like attainment at all ages

of acquisition. In their argument against cut-offs, Muñoz and Singleton (2011) additionally argue that (mono-lingual) native speakers are generally not a good comparison point for second language learners success in learning a language since monolinguals and bilinguals are inherently different. Instead, early and late bilinguals can be compared to one another. I discuss some of the experimental evidence for and against critical periods in the next two paragraphs.

A number of studies have shown support of a critical period, the results of a few of which I summarized in the following paragraph. In a seminal study, Johnson and Newport (1989) showed evidence of age of arrival (AoAr) playing a role in language acquisition, looking at Korean and Chinese learners of English as second language. Early learners performed better (more native-like) on grammaticality judgments than late learners. In addition, age of arrival correlated with performance up until the age of 17 (maturation) and not afterwards. Those who acquired their L2 of after this age all performed more poorly. Birdsong and Molis (2001) built on the study by Johnson and Newport (1989) and showed further evidence of maturational effects for a critical period and a negative correlation between L2 performance and AoAr (L1 Korean, Chinese, Spanish; L2 English). There were however some late acquirers with native like responses in the study by Birdsong and Molis (2001).

On the other hand, evidence from a number of studies suggests that at least certain features of a language can be mastered completely by late learners and that there may be no biological differences between late and early learners. In an fMRI study Perani et al. (1998) compared cerebral activation in L2 and native speakers listening to a story (languages investigated were English and Italian; and Spanish and Catalan). High proficient speakers did not differ from native speakers, regardless of age of acquisition (AoAq). Age of arrival only played a role for low proficiency speakers. In a behavioral study, Flege et al. (1999) tested correlation between foreign accent and grammaticality judgments and age of arrival. Age of arrival correlated with foreign accent, but not with grammaticality judgments, once adjusted for confounding variables such as years of education and length of stay (L1 Korean,

L2 English). The authors argue that studies that do find AoA¹ effect are not accounting for these confounds.

In summary, there is evidence suggesting AoA plays a role in acquisition of an L2. However, at least in some cases, complete acquisition is possible across AoA, refuting at least the strictest biological theory of a critical period. (See Herschensohn 2007 for a review and further support of individual differences in complete acquisition at late AoA). In this study, participants vary across age of acquisition and age of arrival. Experiment 3 investigates AoA correlates with reading mechanisms by L1 concatenative speakers in their L2, Hebrew.

7.2.2 Transfer Effects

As learners acquire a new language, they may rely on structures or processing techniques from their native language. This is called ‘the transfer effect’, in which features or processes from the L1 are present in the L2. These effects may be transient, visible only at earlier stages of acquisition or may be longer lived still present with proficient speakers.

For instance, Sabourin et al. (2006) found evidence in favor of a transfer effect for learning grammatical gender in L2 Dutch. They performed two tasks, one untimed (offline) and another timed (online). In the offline task all participants performed well (above 80%) regardless of first language. However, in the timed pronoun agreement task, L2 speakers performed in accordance with the similarity of their L1 gender system to the target Dutch one. Native German speakers with similar L1 gender performed the best, followed by L1 Romance speakers who have a gender system that differs and finally English speakers whose L1 has no gender performed the worst. Thus, transfer from L1 was observed at least in real-time processing. Transfer effects are not ubiquitous, however, and there are arguments against it (e.g. Papadopoulou and Clahsen 2003 shows that while L2 speakers of Greek differ in processing of relative clauses from native speakers, these differences are not reflective of

¹Some of the studies have investigated age of arrival, while others investigated age of acquisition. This depends on different factors such as whether testing was conducted in the country of the L2 or L1, whether speakers who immigrated had previous exposure to the L2, etc. In this dissertation, I use AoA to refer to both age of acquisition and age of arrival, as differentiated from AoAq and AoAr respectively.

their L1; see Clahsen and Felser (2006) for further discussion.

This study investigates the transfer of L1 reading mechanisms, rather than grammatical structures. The readers in this study are all relatively successful in terms of the act of reading and certainly proficient enough to read Hebrew without vowels. It is unclear, however, whether they read in the same way that native speakers do or if they use strategies from their L1.

7.2.3 Masked Priming in a Second Language

The masked priming technique is especially useful for investigation of morphological priming and is essential for transposed letter priming so that recovery cannot be attributed to conscious manipulations. For this reason, it is the chosen method for this experiment. A potential concern might be that this style of presentation is too difficult for L2 readers. However, a number of studies have successfully used this method.

Silva and Clahsen (2008) found both identity and morphological priming for L2 speakers of English whose L1s were Chinese and German. Thus masked priming was possible even when the L2 differed significantly from the L1. Yu-Cheng Lin et al. (2015) looked at TL priming in L2 English for readers whose first language was Spanish; TL masked priming effects were observed for L2 readers. In that study, masked priming is used in order to look at letter position flexibility through TL primes in a paradigm identical to that used for native speakers.

7.2.4 General Research Questions

In this study, I investigate the role of morphology (root templatic vs. concatenative) in reading by L2 speakers of Hebrew whose native language is concatenative using the same masked priming experiment as in Chapter 4. In particular, I look at letter position flexibility for root letters in nouns (Experiment 1) and verbs (Experiment 2) in Hebrew. The results of Chapter 4 indicate that native Hebrew speakers are sensitive to root letter position in nouns, but not in verbs. In this study, I explore whether proficient L2 readers of Hebrew

have acquired this same mechanism or not. If readers are using the mechanism of their L1 for reading, where stems are not parsed, I predict letter position flexibility for both nouns and verbs. However, if L2 readers adopted the mechanism of the L2, letter position flexibility for the root would only be present for nouns and not verbs.

Experiments 1 and 2 (Sections 7.3 and 7.4) look at learners as a group without investigating individual differences. While, this approach is a useful one for looking at general priming effects it masks variation among speakers. The goal of Section 7.5 is to investigate whether such differences are a result of age of acquisition and/or age of arrival.

Rather than studying reading speed or comprehension, this study compares reading mechanisms between native speakers and L2 speakers of Hebrew. That is, even if L2 learners, perform similarly to Hebrew speakers, do they use the same methods of achieving these results or is there transfer from their L1?² Additionally, does the choice of mechanism depend on AoA?

7.3 Experiment 1: Root Transposition in Nouns

This experiment investigates letter position flexibility in roots of templatic nouns in non-native speakers of Hebrew whose L1 is a concatenative language. Recall from Velan and Frost (2009) and the results of Chapter 4 that native Hebrew speakers are sensitive to root letter position in nouns. Nouns with transposed root letters do not prime. In contrast, across concatenative languages, where the stem is not decomposed, letter position is flexible in nouns (e.g.?). The L2 speakers may be using reading mechanisms from their L1 (in which stems are processed as a whole and there is letter flexibility across stem letters) or they may have acquired this L2 mechanism of Hebrew. Acquisition of the mechanism may also depend on Age of Acquisition, which is explored further in Experiment 3 (Section 7.5).

This experiment investigates whether or not root letter position is flexible in nouns for

²Advanced learners achieved comparable accuracy for word-non word lexical decision. This experiment then focuses on the mechanism by which they achieve these results as the results themselves are similar to that of native speakers.

L2 Hebrew speakers whose L1 is concatenative. If the second language readers are using the same mechanisms as native speakers, I expect transposed words not to prime for the learners just as with native speakers. On the other hand, if non-native speakers are reverting to L1 mechanisms, letter position may remain flexible and there would be a priming effect in the TL condition.

7.3.1 Methods

The following section outlines the methods in Experiment 1; many of which also apply to Experiment 2.

Participants

Thirty eight native speakers of concatenative languages participated in both experiments in this study. Of these 35 are native Russian speakers and 3 are native English speakers. The participants had a minimum reading proficiency of being able to read in Hebrew without vowels.³ All subjects had immigrated to Israel; 35 of them currently live in Israel and 3 have subsequently moved to the U.S. and were tested there. Those who arrived after school age all participated in government subsidized Hebrew immersion classes called Ulpan. Average age of participants was 35, ranging from 23 to 65.

Participants were asked to self-report Hebrew proficiency in reading, speech, writing and comprehension on a 7 point scale with 1 indicating they can only use a limited number of words and 7 indicating native-like ability. On average, participants had a score of 6 out of 7 for all types of proficiency (see Table 7.1) and a median proficiency of 7.

Proficiency as a correlate of individual differences is not investigated in this study since self-reported proficiency was uniformly high and no independent measures were taken. Individual differences are investigated in relation to age of arrival and acquisition. This allows for a measure of the AoA effect on reading use of native vs L2 reading mechanisms.

³While Hebrew is typically written without most vowels as described in Chapter 2, second language learners and child learners often rely on vowels while learning to read.

TABLE 7.1: General Subject Info: Age of acquisition, age of arrival in Israel

	Avg	Min	Max
Age of Acquisition	13	3	32
Age of Arrival	17	2	60
Reading	6	2	7
Speech	6	3	7
Writing	6	1	7
Comprehension	6	3	7
Avg Proficiency	6	2	7
Years in Israel	18	1.5	27

I report on data from 26 (of the 38) subjects for Experiment 1. Subjects who had more than 4 errors for any of the prime types in this experiment were excluded; a description of exclusion criteria follows in section 7.3.2.

7.3.2 *Stimuli*

There are a total of 24 nouns in this condition.⁴ Stimuli were selected from a first and second level Hebrew Ulpan textbook to increase likelihood of participant familiarity with words.⁵ Three types of primes are used: an identity, unrelated and transposed letter with 8 of each type of prime per subject. Three lists were used in a Latin square design so that across subjects each word was primed by each prime type.

In the transposed letter condition, two (of three) adjacent root letters were transposed. Transposition position was shifted to occur both between first and second, as well as second

⁴These nouns have higher written frequency than those used with native speakers. However, given the variable language experiences of L2 speakers, these types of frequency measures rarely reflect the same exposure level for native versus non-native speakers.

⁵Ulpan has five levels, each of which has sub-levels. The first two are the most basic levels typically attended by those who had little to no Hebrew exposure before arriving in Israel.

and third root letters. In the unrelated condition, two root letters were substituted with other letters, creating a non-word. The letters that were substituted in the unrelated condition were the same as those transposed in a different list. All transpositions occurred word internally.

TABLE 7.2: Stimuli with Transposed Root Letters

	Identity	TL	Unrelated
Prime	PiTaRON	PiRaTON	PiMaSON
	PTRON	<u>P</u>RTON	PSMON
Target	PiTaRON	PiTaRON	PiTaRON
	PTRON	PTRON	PTRON

An example word meaning ‘solution’ with the three possible primes. Bolded italicized letters are the root letters. Transposed letters are underlined.

Procedure

The procedure is in line with a masked priming design, following Forster et al. (1987). The task was to make a lexical decision using a button press. Participants were asked to press the ‘yes’ button if the target is a word, and the ‘no’ button if it isn’t one, with response buttons on opposite sides of the button box. They were instructed to answer as quickly as possible without making mistakes. Participants were not explicitly told about the existence of primes.

The experiment was administered in a quiet location using the same laptop computer. PsychoPy software (Peirce 2008, 2007) was used for stimuli presentation. An ioLab button box was used to collect RTs with 1 millisecond resolution, measuring from presentation of the target to subject reaction. Stimuli were presented at the center of the screen. Participants

first saw the forward mask presented for 500 ms. This was followed by a prime presented for 60 ms and then immediately followed by the target. The target remained on the screen until subjects made a lexical decision by button press. The lag between the button press and the next stimulus is 1000 ms. Stimuli were presented in David font. Primes are 25% smaller than targets to set them apart.

A prime presentation time of 50 ms was chosen for this experiment. Previous masked priming experiments reported using presentation times ranging from 50-60 ms. For instance, Yu-Cheng Lin et al. (2015) and Midgley et al. (2009) used a 50 ms presentation time, while Silva and Clahsen (2008) reported a 60 ms presentation time. Due to the 60Hz refresh rate of the computer used for presentation, only a 50 ms or 67 ms presentation was possible. The 50 ms time was chosen since it had worked for a number of L2 masked priming studies and because this study included faster readers due to their early AoA and high proficiency. Thus a shorter presentation time was preferable to ensure masking occurred.

All words and non-words from Experiment 1 and 2 as well as stimuli from three other experiments not reported on here were presented together, serving as fillers for one another. Words were presented 24 at a time followed by a break during which a smiley face appeared on the screen for five seconds followed by a five second countdown.

Analysis

Data were analyzed using linear mixed effects models using in R (Pinheiro et al. 2009) using the packages lme4 (Bates et al. 2013) and languageR (Baayen et al. 2011;Baayen 2008), with p-values calculated using the lmerTest (Kuznetsova et al. 2014). I present p-values, significant at $p \leq 0.05$.

Words for which the subject made an error in lexical decision were excluded. In order for a subject to be included in the experiment, s/he needed to have at least 4 correct instances of each prime type (ID, TL and UR). If a subject had more than 4 errors for any of these,

s/he was excluded from the experiment.⁶

Normality and homogeneity were verified by visual inspections of plots of residuals against fitted values. Log transform was used in a case where the normality requirement was not met. Models were compared using likelihood ratio tests with null models consisting of only the random effects to determine the validity of a linear mixed effects model. Models in which the fixed effects model did not differ from the null model were rejected.

7.3.3 Results

The average RT across subjects for the ID condition was 125 ms shorter than the Unrelated Condition ($p < .013$). In the TL condition, RT was 94ms shorter than the Unrelated condition ($p < 0.062$). However, upon visual inspection, the RTs did not appear to be normally distributed. Log transformation was performed and the new p values are ($p < 0.005$) for ID and ($p < 0.043$) for TL. (See results summarized in Table 7.3).

TABLE 7.3: Reaction and prime times for target words in Experiment 1. Priming as compared to unrelated.

	ID	TL	UR
RT (ms)	968	999	1093
Priming	+126*	+94(*7)	

* $p < .05$

7.3.4 Discussion

As a group, L2 readers showed a priming effect for words with TL in root letters in nouns. They are not sensitive to root letter position in nouns and can still retrieve the word with

⁶Experiment 1 has fewer subjects (26) than the Experiment 2 (36) due to an error with one of the lists. This resulted in fewer than 4 ID primed instances for 13 subjects for Experiment 1, whose data were excluded as a result.

those letters transposed. This can be taken evidence of transfer from the L1. Native Hebrew readers are sensitive to root letter position, while in Russian and English letter position in nouns is flexible. This suggests that the role of the root in recognizing nouns is of lesser importance to L2 readers. Given that L2 readers are unlikely to be more successful in root recovery than native speakers, the retrieval likely occurs without relying on root information in particular. It follows that L2 readers are not parsing nouns into roots and templates as native speakers do. Instead they access the word as a whole.

An alternate explanation could be that L2 readers have access to both whole-word and separate root and template representations. It is possible that in typical word recognition, L2 readers rely primarily on root and template activation to recognize templatic words, just as L1 Hebrew speakers do. However, they may also have a second (slower) route by which they can access the whole stem form. In a situation in which the decomposition route does not reach threshold activation, as is the case when root letters in a noun are transposed, readers may rely on the slower whole-stem route.

7.4 Experiment 2: Root Transpositions in Verbs

In Experiment 2, root transpositions occur in verbs. Unlike with nouns, letter position is flexible in both templatic and concatenative languages. L2 speakers are predicted to be primed by transposed root letters just like native Hebrew speakers.

7.4.1 Methods

Methods in Experiment 2 are nearly identical to Experiment 1. Any differences are outlined in this section.

Of the 38 subjects in the overall study, 36 were included in this experiment. Stimuli are of a similar design to Experiment 1. The only difference is that the words in this experiment are all verbs, whereas, those in Experiment 1 are nouns. Procedure and analysis are the same as in Experiment 1.

7.4.2 Results

TABLE 7.4: Reaction and prime times for target words in Experiment 2. Priming as compared to unrelated

	ID	TL	UR
RT (ms)	1060	1070	1174
Priming	+114*	+103*	

* $p < .05$

7.4.3 Discussion

As predicted, participants were primed by TL and ID in verbs. This result does not reflect on transfer mechanisms as it may be reflective of either acquisition of the L2 mechanism or transfer of the L1 mechanism given that both predict the same behavior. It is possible that L2 readers are parsing the words into roots and templates as native speakers do. It is also possible that the second language readers are reading the words holistically as they do with an L1.

To further investigate the question of transfer, morphological priming by root and template should be investigated in a further study. If for L2 speakers, just as native speakers, verbs are primed in a masked paradigm by both roots and templates (Deutsch et al. 1998), it would suggest that like native speakers, L2 learners also parse verbs during reading.

7.5 Age of Acquisition and Arrival as Predictors of Individual Differences-An Individual Differences Analysis of Experiments 1 and 2

In this section individual differences were investigated for both Experiments 1 and 2. The goal was to determine whether age of acquisition and/or arrival in Israel correlated with size of priming effects. The correlation between each of these factors and priming effect (the

difference in reaction time between UR and ID and TL primes) was measured. This section allows for assessing whether the observed results of Experiment 1 and 2 would be expected across ages of acquisition and proficiency levels.

Traditionally, priming studies have looked at the subject group as a whole. However, individual differences can also be measured. This is done by looking at the relative size of a priming effect in correlation with a factor of interest. Typically these studies have looked at reading proficiency and prime size. This has been investigated for readers in their L1. Beyersmann et al. (2015) found that L1 reading proficiency (spelling and vocabulary scores) correlated with morphological priming effect size for non-words consisting of a novel combination of a stem and affix priming the embedded stem as a target in French (e.g. *stronging* priming *strong*). In native readers of Spanish, Duñabeitia et al. (2014) found that faster readers' reading speed correlated with priming effect for between morpheme TL masked priming in Spanish.

Both age of arrival and age of acquisition are considered in this analysis due to the status of Hebrew as both a religious and cultural language in addition to the official language of the state of Israel. Some of the people who immigrated to Israel only achieved proficiency after immigration, but may have learned to read and write at a younger age through religious/cultural schools or classes in their countries of birth. Age of acquisition here is then more reflective of age of exposure, while age of arrival is tied to acquiring proficiency.

Self-reported proficiency was also initially considered as a factor to consider in correlations with prime size. However, due to the uniformly high self-reported proficiency (a median score of 7 out of 7 for all proficiency types), this factor was not variable enough to reliably test for correlations.

7.5.1 Predictions

For the ID condition in both roots and nouns, I do not predict any correlation between priming effects and age of acquisition or arrival. The prime size in the ID condition reflects a general priming effect rather than a difference in morphological processing. Speed of read-

ing is generally correlated more with proficiency than age of acquisition (CITE). Speed of reading is partially accounted for with normalization of reaction times by dividing by the average RT for that subject. Furthermore, self-reported proficiency is high across subjects.

Root Transposition in Nouns

The results of Experiment 1 suggest that as a group L2 speakers can read nouns with root letters transposed with comparable facilitation to non-transposed ID primes. This is in contrast to native Hebrew speakers, who are sensitive to letter position of root nouns. It is not clear, however, whether all speakers have letter position flexibility for nouns or if this varies by speaker. I predict that early acquirers may behave more native like, while later acquirers do not. Alternatively, there may be no correlation between age of acquisition or arrival and priming effect size. Some later acquirers may also have native like mechanisms, while earlier acquirers may pattern differently. Subjects in this experiment have similar demographics for proficiency (see Tables 7.5 and 7.6)

TABLE 7.5: General Subject Info for 26 Subjects on Root Transpositions in Nouns: Age of acquisition, age of arrival in Israel

	Avg	Min	Max
Age of Acquisition	12	3	32
Age of Arrival	18	4.5	60
Reading	6	2	7
Speech	6	3	7
Writing	6	1	7
Comprehension	6	3	7
Avg Proficiency	6	3	7
Years in Israel	17	1.5	26

Root Transposition in Verbs

For the root transposition experiment, I did not predict a correlation between age of acquisition or arrival with prime size. In Hebrew, as well as in Russian and English, there is letter position flexibility for verbs. Second language learners in Experiment 2 as a group had a priming effect as predicted in the TL condition for root transpositions in verbs as did native Hebrew speakers (Chapter 4). The majority (36 out of 38) of the overall subjects participated in this experiment and their proficiency and age of acquisition and arrival demographics were similar to those of the group and those in Experiment 2 (See Tables 7.6 and 7.5).

TABLE 7.6: General Subject Info for 35 Subjects for Root Transpositions in Verbs: Age of acquisition, age of arrival in Israel

	Avg	Min	Max
Age of Acquisition	13	3	32
Age of Arrival	17	2	60
Reading	6	2	7
Speech	6	3	7
Writing	6	1	7
Comprehension	6	3	7
Avg Proficiency	6	3	7
Years in Israel	19	2	27

7.5.2 Methods

Priming Effect

The dependent variable in all comparisons is the priming effect. A priming effect was calculated for each subject in Experiments 1 and 2, for both the ID and TL priming conditions. This was calculated by subtracting UR reaction time from the ID reaction time for the ID

condition and from TL for the TL condition. The priming effect was subsequently normalized to account for differences in average reaction time among subjects. The differences in reaction time were divided by the average reaction time. In this way differences were proportional to average RT and more likely to reflect significant differences. In contrast, the un-adjusted differences reflected the size of average RT for the subject, rather than size of effect.

Analysis

Correlations were measured between ID and TL priming effects from experiments 1 and 2 and the following independent variables (1) Age of Acquisition of Hebrew and (2) Age of Arrival in Israel. All correlations were assessed using a linear regression model in R using the `lm` function. They were also plotted in R.

7.5.3 Results

There was no significant correlation between age of arrival and ID priming effects for either the root transpositions in nouns ($R^2=0.03073$, $p<0.43$) or verbs ($R^2=0.03338$, $p<0.29$). Age of acquisition and ID priming effect also did not correlate significantly for nouns ($R^2=0.04393$, $p<0.34$) or verbs ($R^2=3.74e-05$, $p<0.98$).

Root Transpositions in Nouns

In root transpositions in nouns, age of acquisition did not correlate with priming effect ($(R)^2=0.0437$, $p<0.34$). This is illustrated in Figure 7.1. Age of arrival also did not correlate with priming effect in TL ($(R)^2=0.02641$, $p<0.46$). See Figure 7.2 for an illustration.

7.5.4 Root Transpositions in Verbs

In verbs, a slight, but significant negative correlation was found between age of acquisition and TL priming effect ($(R)^2=0.1635$, $p<0.015$). Such a correlation was also found for age of

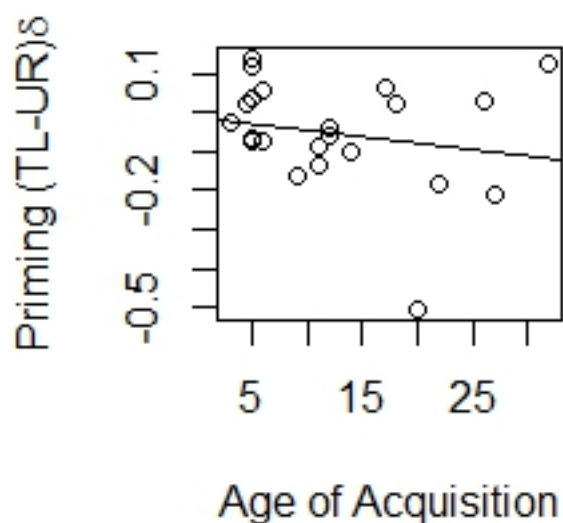


FIGURE 7.1: Transposed Letter Priming effects normalized by subject (ID-TL/Average RT) by Age of Acquisition in root transpositions of nouns

arrival ($(R)^2=0.1196$, $p<0.039$).

7.5.5 Discussion

Overall, as predicted there were no significant correlations between ID priming effect and either AoAq or AoAr.

AoA and TL in Nouns

Neither age of acquisition or age of arrival correlated with priming effect for TL in nouns. However, looking at Figures 7.1 and 7.2, there were early learners in 0-10 AoAq and AoAr

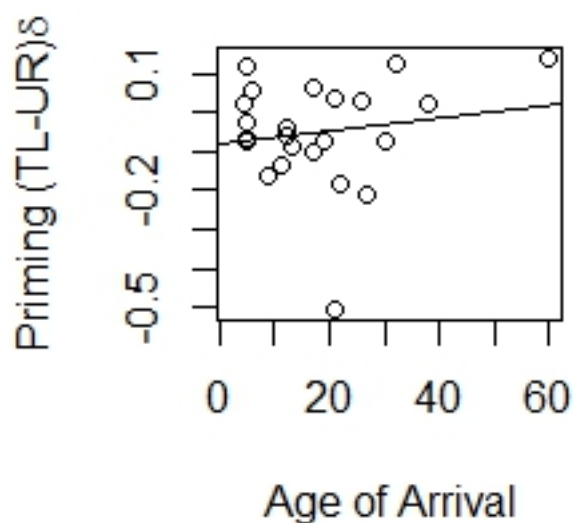


FIGURE 7.2: Transposed Letter Priming effects normalized by subject (ID-TL/Average RT) by Age of Arrival in root transpositions of nouns

ranges who had no priming for TL in nouns.⁸ This is consistent with the results for a native speaker. There are individuals with no priming effects at later AoAr and AoAq times as well, however. This suggests that even at a later AoA readers may acquire native reading mechanisms. It is important to note that these readers as a group are proficient. AoA effects may be more present in a less proficient group. There may be other factors that are better predictors of reading mechanism such as the percentage of time a person uses their L1 versus L2, which should be considered in future studies.

AoA and TL in Verbs

⁸Given the normalization of RT, it is difficult to interpret the significance of small priming effects. However, any effects at zero or higher are consistent with no priming.

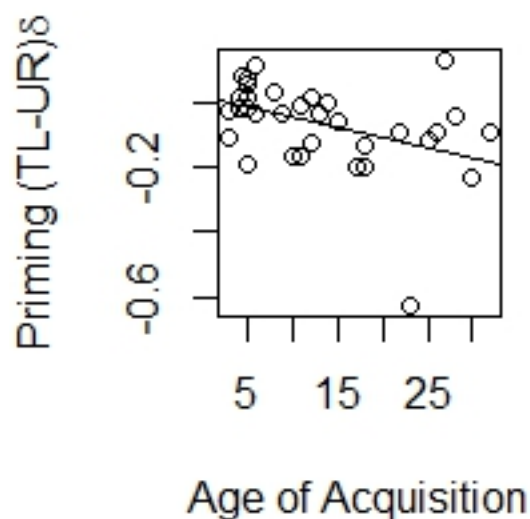


FIGURE 7.3: Transposed Letter Priming effects normalized by subject (ID-TL/Average RT) by Age of Acquisition in root transpositions of verbs

Very slight effects of both age of acquisition and arrival were found for verbs, with a negative correlation between both types of AoA and TL priming effect. The size of the priming effect increases with age of arrival and acquisition. This is somewhat surprising, given that a larger priming effect may be expected for more proficient readers, however the normalization may have accounted for this difference. It is possible, that in fact there is a difference in the prime size depending on reading mechanism. That is, those who read the word as a whole (the native mechanism of their L1) have a larger priming effect than those who parse it (the native mechanism of their L2). If this is the case, AoA may correlate very slightly with reading mechanism selection, where early AoA readers are more likely to be using the L2 mechanism, while later AoA readers are more likely to revert to their L1 mechanism. This however cannot be determined from the current results. Further investigation

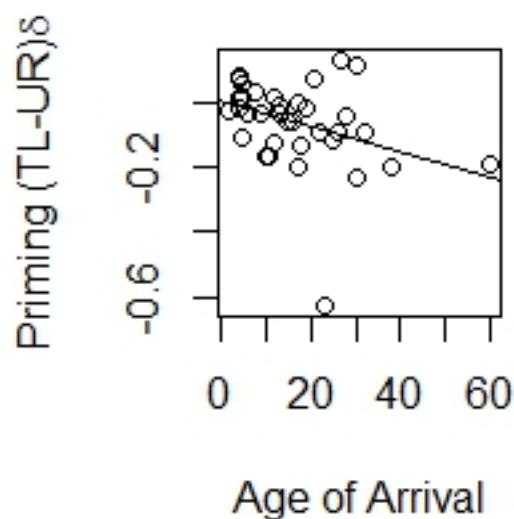


FIGURE 7.4: Transposed Letter Priming effects normalized by subject (ID-TL/Average RT) by Age of Arrival in root transpositions of verbs

is necessary to parse out these possibilities.

A general drawback of this study was the relatively small sample size, the clustering of AoA and no independent measures of reading proficiency. While these shortcomings cannot be addressed here, they are important considerations for future studies.

7.5.6 *General Discussion and Further Directions*

The results of this study suggest that even proficient early acquirers may retain some of their morphological processing from their L1. This is evidence for language transfer of processing routines. Crucially, given that most of the early acquirers did not learn to read in their L1 before learning to do so in their L2, these differences reflect general morphological processing

and not just reading mechanisms.

AoA did not appear to play a role for whether readers used native like reading mechanisms for nouns. Factors such as high overall reading proficiency among the subjects may have masked some of these effects. That is, there may be AoA effects among less proficient readers. In addition to the concrete findings of this study, it also shows that the masked priming paradigm can be used to investigate reading in Hebrew as an L2 for speakers of a concatenative language such as Russian.

In future studies, I plan to look at root and template priming for both nouns and verbs in Hebrew as an L2 for further evidence of whether L2 readers use native like mechanisms for reading. In particular, I would like to investigate whether there is evidence of parsing into nouns and templates for verbs and for nouns. I would have a larger sample size to be able to better assess individual differences and would have independent measures of reading proficiency in addition to self-report.

I also plan to use the ERP paradigm from Chapter 6, repeating the experiment with speakers of Hebrew as a second language to identify whether they have the same effects for reading templatic vs concatenative words, indicating a default templatic reading strategy. Results of this experiment suggest a difference at least in terms of letter position flexibility between native speakers and learners. The ERP paradigm provides a method for looking at word reading in a more natural context without letter transposition. I would also like to investigate native Hebrew speakers reading a concatenative language as an L2.

Chapter 8

CONCLUSIONS AND FURTHER DIRECTIONS

8.1 Chapter goals

In this chapter, I revisit the research questions set-out in Chapter 1 and suggest some future research directions.

8.2 General Discussion and Conclusions

Overall, the results of this dissertation support the claim that templatic stems in Hebrew are decomposed into roots and templates during word recognition. In fact templatic decomposition appears to be the default reading strategy for Hebrew stems (Chapter 6). The root in particular plays an important role in word recognition in nouns, while in verbs both the root and the template are important (Chapter 4). Furthermore, morphological processing is shown to be important to auditory word recognition as well as visual recognition (Chapter 5). As with concatenative languages, there is also evidence of decomposition of inflectionally affixed words into stems and affixes. Thus, the results of the studies conducted in this dissertation lend support to templatic and affixational morphology playing an important role in word recognition in Hebrew as a templatic language. Finally, in investigating second language learners of Hebrew, there is evidence of transfer in reading mechanism from the concatenative L1 even when readers are proficient (Chapter 7).

I discuss the main findings of the dissertation in terms of the research questions laid out in Chapter 1 in more detail below.

8.2.1 Role of the Root and Template in Templatic word Recognition and Interaction with Lexical Category

The results of Chapter 4 show that letter position inflexibility is not uniform across templatic words as had been suggested by results of previous work (e.g. Velan and Frost 2009). Rather, it differs depending on morpheme (root vs. template) and lexical category (verb vs. noun). These differences in flexibility provides insight into the role of each of the morphemes in word recognition.

In particular, a noun with transposed root letters does not prime. However, a noun with transpositions between root and template letters, in which root letters retain their relative order, does prime. These results suggest that root information is particularly important to noun recognition. In contrast, verbs with either root or template letters transposed does prime. However, transpositions between root and templates do not prime. Thus for verbs, easy access to either root or template allows for recognition, suggesting that both play important roles in recognition. I discuss theoretical implications of these results in Section 8.2.5.

8.2.2 Role of Morphology Across Modalities: Visual vs. Auditory

Research on word recognition in templatic languages has primarily focused on the visual domain. One of the goals of this dissertation was to investigate whether the role of templatic morphology was specific to visual word recognition or whether it is more general mechanism extending to the auditory domain as well. Results of the phoneme restoration studies in Chapter 5 suggest that just as in visual word recognition, morphology plays an important role in auditory word recognition.

Hebrew readers have been shown to have separate reading mechanisms for concatenative and templatic words, where concatenative borrowings are letter position flexible (unlike templatic words) and thus does not seem to be parsed during reading Velan and Frost (2011). The results of the first study in Chapter 5 suggest that the same is true for auditory word

recognition, where a concatenative word with noise masking a sound is easier to recover than a templatic word with analogous masking. Furthermore, just as roots play an important role in visual noun recognition, they do so in auditory recognition as well. Nouns with root sounds masked are more difficult to recover than those with template sounds masked. Together, these results indicate that the role of templatic morphology in word recognition is modality independent.

8.2.3 Decomposition as a Default Mechanism for Hebrew Stems

While, in concatenative languages, (unaffixed) stems are all monomorphemic, most words (excluding borrowings) in a templatic language are complex consisting of a root and template. Given the prevalence of these words, it is possible that the default recognition mechanism for stems involves a decomposition or parsing component. In order to test this, I compared reading of templatic words with concatenative borrowings in the ERP paradigm (Chapter 6).

Clear differences in amplitude were observed between the in the (200-300 ms) with greater amplitudes for concatenative than templatic words. The greater amplitude suggests a greater processing cost for reading of concatenative words than of templatic ones. It is suggestive of stem parsing being the default mechanism in a language where most stems are composed of two morphemes: a template and a root.

8.2.4 Inflectional Affixation in a Templatic Language

Inflectional affixation has been investigated in concatenative languages with clear evidence emerging of decomposition into stems and affixes (e.g. Taft 2004). This type of affixation had not been looked at in templatic languages, however, in which the stems themselves are inherently complex, consisting of roots and templates.

Using the ERP paradigm, I found evidence for templatic affixed words undergoing decomposition (Chapter 4). Inflectionally affixed words had a greater amplitude N400 than

un-inflected ones, suggestive of processing costs in that time-window. These results are analogous to the findings in Finnish, a concatenative language (e.g. Leinonen et al. 2009). In addition, reaction times for affixed words were longer than those of unaffixed words, also suggestive of decomposition. Thus Hebrew readers appear to decompose inflected words just as concatenative readers do.

8.2.5 *Theoretical Implications*

The most important theoretical implication that can be concluded from this dissertation is that both templatic and inflectional morphology do indeed play an important role in Hebrew word recognition and that this extends to both the auditory and visual domains. In considering universal models of word recognition, in either modality it is then important to consider this type of morphological processing as part of the model. While some models already incorporate complexity in the form of affixation, which can be found in other languages, it is important to consider templatic complexity more specifically. Unlike affixal morphology, templatic morphology is not linear, but rather intertwined. Furthermore, roots and templates compose the stems themselves. Thus, even the stem templatic languages is not processed holistically as is done in concatenative languages. Given the evidence of the role that roots and templates play in word recognition, it is important to amend any model that claims to be universal to account for this type of complexity.

I propose some specific implications and mechanisms for word recognition in Hebrew as a templatic language as well as future experiments to test these claims. These processes can be applied to any compatible model. I describe them here in terms of activation and search probabilities in accessing a mental lexicon during visual word recognition as an example framework in order to better explain the specific claims; however this could be adapted to other types of models as well, including auditory ones. In terms of affixational complexity, the results of this dissertation suggest that inflectionally affixed words are decomposed in Hebrew as part of either a dual route or full decomposition approach identical to that of other concatenative languages and is not discussed further here.

Evidence from this dissertation and previous research points to the lexicon for Hebrew consisting of representation of roots, templates, whole-stem forms for concatenative words and (inflectional) affixes. During word recognition, matching stems and morphemes representations are activated. In order for recognition to occur, the sum of constituent morpheme activation must reach a threshold. For templatic words, this is the root and template, while for concatenative words this is the just the stem.¹ In addition, orthographic neighbors, closely matching roots and templates are also weakly activated, such that words with transposed letters may reach threshold recognition. Furthermore, I propose that more frequent roots and templates have higher activation in line with frequency effects proposed in other models of recognition (e.g. Taft 2004).²

The proposed explanation accounts for the different roles that roots and templates play in word recognition for roots and nouns. Since verb templates are more productive and frequent, they have strong activation. As a result it is possible to reach a recognition threshold with a strongly activated template and a weakly activated root in a case when root letters are transposed. Furthermore, given that roots are not compatible with every possible verb template (e.g. the reflexive template is not compatible with the root meaning *speak*), a strongly activated verb template helps decrease the search space and narrow down on the correct orthographic neighbor. In contrast, noun templates are less productive and frequent and would receive less activation. A weakly activated root and a normally activated template then are unable to reach . Unlike verb templates, noun templates are greater in number, less productive and do not carry grammatical functions that would help narrow the search space to the same extent.

The claims laid out here about nouns and verbs could be directly tested by selecting

¹As mentioned in Chapter 6, it is possible that templatic words also have a full stem representation. If that is the case, it would be necessary to account for the differences in letter position flexibility between concatenative and templatic words.

²Note while I do not have specific results of frequency effects for Hebrew, there is widespread evidence of word and morpheme frequency on word recognition (e.g. Taft 1979, Sereno et al. 1998, Dambacher et al. 2006).

nouns and verbs with matching root and template frequency and comparing letter position flexibility of roots and templates between them. The prediction, given this proposed mechanism, would be that letter position flexibility of roots and templates would be equivalent for these.

8.2.6 Reading Hebrew as a Second Language: Transfer from Concatenative Languages

Given the observed differences in word recognition mechanisms for concatenative vs templatic languages, the final the final goal of the dissertation was to investigate how second language learners of Hebrew acquired the morphological reading mechanism. In particular, I investigated whether there was transfer from the L1 as had been observed in other languages, particularly in online processing (e.g. Sabourin et al. 2006). Furthermore, I investigated whether age of acquisition or arrival correlated with transfer.

The findings of the study described in Chapter 7 suggested that there is transfer from the L1, with even proficient readers of Hebrew relying on morphological strategies from their concatenative L1 for reading. Unlike the native Hebrew readers described in section 8.2.1, the second language readers as a group were not sensitive to letter position flexibility of root letters in nouns; nouns with root letters transposed did prime. Thus there is transfer from the concatenative L1, such that readers at least have the option to read templatic words holistically. There was no correlation between transfer and either age of acquisition or arrival.

8.3 Future Directions

I propose a number of future directions for investigation, some of which I have discussed throughout the chapters; I summarize some of these here.

One set of future directions is a further exploration of the auditory domain of word recognition in Hebrew. I plan a replication of the ERP study in Chapter 6 using auditory stimuli. I predict that similar effects will be observed in the auditory domain as those in the visual one. Another approach, I plan to take is to look at the relationship between morphology

and complex uniqueness point in Hebrew as a language with a non-linear morphology. In particular, I predict two different uniqueness points for Hebrew un-affixed nouns: one at the point of divergence, as with other concatenative languages, and one at the point where root information can be retrieved. Combining eye-tracking and an auditory signal, it would be possible to further explore the role of morphology as well as the time-course of auditory recognition. This could be done for instance in a picture matching task, where a subject is asked to select a picture matching the word they hear; in addition to the target picture, pictures may represent words sharing either a root or template with the target word. I predict extended gaze fixation for words sharing a root for nouns and for those sharing both a root and template for verbs.

In addition, I would like to use the ERP paradigm from this study to further investigate reading Hebrew as an L2 with non-native Hebrew speakers participating in a replication of the experiment from Chapter 6. I predict that readers of Hebrew as a second language will not exhibit a difference between reading concatenative and templatic words as native speakers did. In addition, I would like to compare the same native Hebrew speakers reading Hebrew stimuli as in Chapter 6 as well as English stimuli, similar to those used by Lavric et al. (2012) to test whether they behave as native concatenative readers. Given the presence of concatenative words in Hebrew and readers differential treatment of these, I predict that the native Hebrew speakers will not differ from native English speakers.

Finally, making use of the sensitivity of ERP components to frequency effects (e.g. the N400 Barber et al. (2004)), I would like to further compare the role of the root and the template in word recognition of nouns vs. verbs. This can be done by manipulating root and template frequency individually, while maintaining constant stem frequency in both verbs and nouns. I predict a greater (amplitude) frequency effect for templates in verbs versus nouns.

BIBLIOGRAPHY

- Aderman, D. and Smith, E. E. (1971). Expectancy as a determinant of functional units in perceptual recognition. *Cognitive Psychology*, 2(1):117–129.
- Alegre, M. and Gordon, P. (1999). Frequency effects and the representational status of regular inflections. *Journal of memory and language*, 40(1):41–61.
- Baayen, H. and 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.
- Baayen, R. H. (2008). *Analyzing linguistic data: A practical introduction to statistics using R*. Cambridge University Press.
- Baayen, R. H., Dijkstra, T., and 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, R. H., Milin, P., \DJur\ d jević, D. F., Hendrix, P., and Marelli, M. (2011). An amorphous model for morphological processing in visual comprehension based on naive discriminative learning. *Psychological review*, 118(3):438.
- Baayen, R. H. and Schreuder, R. (1995). Morphological Processing. *Encyclopedia of Cognitive Science*.
- Balling, L. W. and Baayen, R. H. (2012). Probability and surprisal in auditory comprehension of morphologically complex words. *Cognition*, 125(1):80–106.

- Balota, D. A., Cortese, M. J., Sergent-Marshall, S. D., Spieler, D. H., and Yap, M. J. (2004). Visual word recognition of single-syllable words. *Journal of Experimental Psychology: General*, 133(2):283.
- Barber, H., Vergara, M., and Carreiras, M. (2004). Syllable-frequency effects in visual word recognition: evidence from ERPs. *Neuroreport*, 15(3):545–548.
- Bates, D., Maechler, M., and Bolker, B. (2013). lme4: Linear mixed-effects models using Eigen and Eigen classes. R package version 0.999999-0. 2012. URL: <http://CRAN.R-project.org/package=lme4>.
- Beyersmann, E., Casalis, S., Ziegler, J. C., and Grainger, J. (2015). Language proficiency and morpho-orthographic segmentation. *Psychonomic bulletin & review*, 22(4):1054–1061.
- Birdsong, D. and Molis, M. (2001). On the evidence for maturational constraints in second-language acquisition. *Journal of Memory and language*, 44(2):235–249.
- Blau, J. (1981). *The renaissance of modern Hebrew and modern standard Arabic: Parallels and differences in the revival of two Semitic languages*, volume 18. Univ of California Press.
- Bohas, G. (1997). *Matrices, étymons, racines: éléments d'une théorie lexicologique du vocabulaire arabe*, volume 8. Peeters Publishers.
- Bohas, G. (1999). Pourquoi et comment se passer de la racine dans l'organisation du lexique de l'arabe. *Bulletin de la Société de Linguistique de Paris*, 94(1):363–402.
- Boudelaa, S. and Marslen-Wilson, W. D. (2001). Morphological units in the Arabic mental lexicon. *Cognition*, 81(1):65–92.

- Boudelaa, S., Pulvermüller, F., Hauk, O., Shtyrov, Y., and Marslen-Wilson, W. (2010). Arabic morphology in the neural language system. *Journal of Cognitive Neuroscience*, 22(5):998–1010.
- Bouma, H. (1973). Visual interference in the parafoveal recognition of initial and final letters of words. *Vision research*, 13(4):767–782.
- Butterworth, B. (1983). *Lexical representation. u: Butterworth B (ur.) Language production, vol. II: Development, writing and other language processes*. New York-San Diego, itd: Academic Press.
- Caramazza, A., Laudanna, A., and Romani, C. (1988). Lexical access and inflectional morphology. *Cognition*, 28(3):297–332.
- Caramazza, A., Miceli, G., Silveri, M. C., and Laudanna, A. (1985). Reading mechanisms and the organisation of the lexicon: Evidence from acquired dyslexia. *Cognitive Neuropsychology*, 2(1):81–114.
- Chialant, D., Caramazza, A., and Feldman, L. B. (1995). Where is morphology and how is it processed? The case of written word recognition. *Morphological aspects of language processing*, pages 55–76.
- Christianson, K., Johnson, R. L., and Rayner, K. (2005). Letter transpositions within and across morphemes. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 31(6):1327.
- Clahsen, H. (1999). Lexical entries and rules of language: A multidisciplinary study of German inflection. *Behavioral and brain sciences*, 22(06):991–1013.
- Clahsen, H. and Felser, C. (2006). Grammatical processing in language learners. *Applied Psycholinguistics*, 27(01):3–42.

- Clarke, J., Gaudrain, E., Chatterjee, M., and Başkent, D. (2014). T'ain't the way you say it, it's what you say—Perceptual continuity of voice and top-down restoration of speech. *Hearing research*, 315:80–87.
- Cole, R. A. and Scott, B. (1974). The phantom in the phoneme: Invariant cues for stop consonants. *Perception & Psychophysics*, 15(1):101–107.
- Coltheart, M., Curtis, B., Atkins, P., and Haller, M. (1993). Models of reading aloud: Dual-route and parallel-distributed-processing approaches. *Psychological review*, 100(4):589.
- Crepaldi, D., Rastle, K., Coltheart, M., and Nickels, L. (2010). 'Fell' primes 'fall', but does 'bell' prime 'ball'? Masked priming with irregularly-inflected primes. *Journal of memory and language*, 63(1):83–99.
- Dambacher, M., Kliegl, R., Hofmann, M., and Jacobs, A. M. (2006). Frequency and predictability effects on event-related potentials during reading. *Brain research*, 1084(1):89–103.
- Daniloff, R. and Moll, K. (1968). Coarticulation of lip rounding. *Journal of Speech and Hearing Research*, 11(4):707.
- Davis, C. J. (2001). *The self-organising lexical acquisition and recognition (SOLAR) model of visual word recognition*. PhD thesis, ProQuest Information & Learning.
- Davis, C. J. (2010a). SOLAR versus SERIOL revisited. *European Journal of Cognitive Psychology*, 22(5):695–724.
- Davis, C. J. (2010b). The spatial coding model of visual word identification. *Psychological review*, 117(3):713.
- De Jong IV, N. H., Schreuder, R., and Harald Baayen, R. (2000). The morphological family size effect and morphology. *Language and cognitive processes*, 15(4-5):329–365.

- Deutsch, A., Frost, R., and 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.
- Duñabeitia, J. A., Perea, M., and Carreiras, M. (2007). Do transposed-letter similarity effects occur at a morpheme level? Evidence for morpho-orthographic decomposition. *Cognition*, 105(3):691–703.
- Duñabeitia, J. A., Perea, M., and Carreiras, M. (2014). Revisiting letter transpositions within and across morphemic boundaries. *Psychonomic bulletin & review*, 21(6):1557–1575.
- Duez, D. (2001). Restoration of deleted and assimilated consonant sequences in conversational French speech: effects of preceding and following context. *Journal of the International Phonetic association*, 31(01):101–114.
- Dufau, S., Grainger, J., and Holcomb, P. J. (2008). An ERP investigation of location invariance in masked repetition priming. *Cognitive, Affective, & Behavioral Neuroscience*, 8(2):222–228.
- Dupoux, E., Pallier, C., Kakehi, K., and Mehler, J. (2001). New evidence for prelexical phonological processing in word recognition. *Language and cognitive processes*, 16(5-6):491–505.
- Edmonds, B. A. and Culling, J. F. (2005). The spatial unmasking of speech: evidence for within-channel processing of interaural time delay. *The Journal of the Acoustical Society of America*, 117(5):3069–3078.
- El Yagoubi, R., Chiarelli, V., Mondini, S., Perrone, G., Danieli, M., and Semenza, C. (2008). Neural correlates of Italian nominal compounds and potential impact of headedness effect: An ERP study. *Cognitive Neuropsychology*, 25(4):559–581.

- Elman, J. L. and McClelland, J. L. (1986). Exploiting lawful variability in the speech wave. *Invariance and variability in speech processes*, 1:360–380.
- Emmorey, K. D. (1989). Auditory morphological priming in the lexicon. *Language and cognitive processes*, 4(2):73–92.
- Farhy, Y., Veríssimo, J., and Clahsen, H. (2017). Universal and particular in morphological processing: Evidence from Hebrew. *The Quarterly Journal of Experimental Psychology*, pages 1–10.
- Farnetani, E. and Recasens, D. (1993). Anticipatory consonant-to-vowel coarticulation in the production of VCV sequences in Italian. *Language and Speech*, 36(2-3):279–302.
- Ferrand, L. and Grainger, J. (1994). Effects of orthography are independent of phonology in masked form priming. *The Quarterly Journal of Experimental Psychology*, 47(2):365–382.
- Fiorentino, R., Naito-Billen, Y., Bost, J., and Fund-Reznicek, E. (2014). Electrophysiological evidence for the morpheme-based combinatoric processing of English compounds. *Cognitive neuropsychology*, 31(1-2):123–146.
- Flege, J. E., Yeni-Komshian, G. H., and Liu, S. (1999). Age constraints on second-language acquisition. *Journal of memory and language*, 41(1):78–104.
- Forster, K. I. (1987). Form-priming with masked primes: The best match hypothesis. *Attention and performance XII: The psychology of reading*, pages 127–146.
- Forster, K. I., Davis, C., Schoknecht, C., and Carter, R. (1987). Masked priming with graphemically related forms: Repetition or partial activation? *The Quarterly Journal of Experimental Psychology*, 39(2):211–251.

- Forster, K. I. and Taft, M. (1994). Bodies, antibodies, and neighborhood-density effects in masked form priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 20(4):844.
- Fowler, C. A. and Saltzman, E. (1993). Coordination and coarticulation in speech production. *Language and speech*, 36(2-3):171–195.
- Frost, R. (2012). A universal approach to modeling visual word recognition and reading: Not only possible, but also inevitable. *Behavioral and Brain Sciences*, 35(05):310–329.
- Frost, R., Deutsch, A., Gilboa, O., Tannenbaum, M., and Marslen-Wilson, W. (2000). Morphological priming: Dissociation of phonological, semantic, and morphological factors. *Memory & Cognition*, 28(8):1277–1288.
- Frost, R., Forster, K. I., and 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.
- Frost, R., Kugler, T., Deutsch, A., and Forster, K. I. (2005). Orthographic Structure Versus Morphological Structure: Principles of Lexical Organization in a Given Language. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 31(6):1293–1326.
- Frost, R. and Plaut, D. (2005). The word-frequency database for printed Hebrew. *Retrieved March*, 21:2005.
- Frost, R., Siegelman, N., Narkiss, A., and Afek, L. (2013). What predicts successful literacy acquisition in a second language? *Psychological science*, 24(7):1243–1252.
- Gaskell, M. G. and 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. and Marslen-Wilson, W. D. (1998). Mechanisms of phonological inference in speech perception. *Journal of Experimental Psychology: Human Perception and Performance*, 24(2):380.
- Goldsmith, J. A. and Club, I. U. B. L. (1976). *Autosegmental phonology*, volume 159. Citeseer.
- Grainger, J. and Ferrand, L. (1994). Phonology and orthography in visual word recognition: Effects of masked homophone primes. *Journal of Memory and Language*, 33(2):218–233.
- Grainger, J. and Holcomb, P. J. (2009). Watching the Word Go by: On the Time-course of Component Processes in Visual Word Recognition. *Language and linguistics compass*, 3(1):128–156.
- Grainger, J., Muneaux, M., Farioli, F., and Ziegler, J. C. (2005). Effects of phonological and orthographic neighbourhood density interact in visual word recognition. *The Quarterly Journal of Experimental Psychology Section A*, 58(6):981–998.
- Grainger, J. and Ziegler, J. (2011). A dual-route approach to orthographic processing. *Frontiers in psychology*, 2:54.
- Granena, G. and Long, M. H. (2013). Age of onset, length of residence, language aptitude, and ultimate L2 attainment in three linguistic domains. *Second Language Research*, 29(3):311–343.
- Groppe, D. M., Choi, M., Huang, T., Schilz, J., Topkins, B., Urbach, T. P., and Kutas, M. (2010). The phonemic restoration effect reveals pre-N400 effect of supportive sentence context in speech perception. *Brain research*, 1361:54–66.
- Grosjean, F. (1980). Spoken word recognition processes and the gating paradigm. *Attention, Perception, & Psychophysics*, 28(4):267–283.

- Guerrera, C. and Forster, K. (2008). Masked form priming with extreme transposition. *Language and Cognitive Processes*, 23(1):117–142.
- Herschensohn, J. R. (2007). *Language development and age*. Cambridge University Press Cambridge.
- Hetzron, R. (1976). Two principles of genetic reconstruction. *Lingua*, 38(2):89–108.
- Hetzron, R. (1998). *The Semitic languages*. Routledge language family descriptions. Routledge, New York.
- Hillenbrand, J. M., Clark, M. J., and Nearey, T. M. (2001). Effects of consonant environment on vowel formant patterns. *The Journal of the Acoustical Society of America*, 109(2):748–763.
- Öhman, S. E. (1966). Coarticulation in VCV utterances: Spectrographic measurements. *The Journal of the Acoustical Society of America*, 39(1):151–168.
- Hoberman, R. D. and Aronoff, M. (2003). The verbal morphology of Maltese. *LANGUAGE ACQUISITION AND LANGUAGE DISORDERS*, 28:61–78.
- Jackson, A. and Morton, J. (1984). Facilitation of auditory word recognition. *Memory & Cognition*, 12(6):568–574.
- Jacobs, A. M., Rey, A., Ziegler, J. C., and Grainger, J. (1998). MROM-p: An interactive activation, multiple readout model of orthographic and phonological processes in visual word recognition. *Localist connectionist approaches to human cognition*.
- Jasper, H. H. (1958). The ten twenty electrode system of the international federation. *Electroencephalography and Clinical Neurophysiology*, 10:371–375.

- Johnson, J. S. and Newport, E. L. (1989). Critical period effects in second language learning: The influence of maturational state on the acquisition of English as a second language. *Cognitive psychology*, 21(1):60–99.
- Johnston, J. C. (1978). A test of the sophisticated guessing theory of word perception. *Cognitive Psychology*, 10(2):123–153.
- Kashino, M. (2006). Phonemic restoration: The brain creates missing speech sounds. *Acoustical Science and Technology*, 27(6):318–321.
- Korinth, S. P., Sommer, W., and Breznitz, Z. (2013). Neuronal response specificity as a marker of reading proficiency: two-fold nature of the N170 revealed after massive repetition. *Neuroreport*, 24(2):96–100.
- Kutas, M., Hillyard, S. A., and others (1980). Reading senseless sentences: Brain potentials reflect semantic incongruity. *Science*, 207(4427):203–205.
- Kuznetsova, A., Brockhoff, P. B., and Christensen, R. H. B. (2014). *lmerTest: tests for random and fixed effects for linear mixed effect models (lmer objects of lme4 package). R package 2.0-11.*
- Laine, M., Niemi, J., Koivuselkä-Sallinen, P., Ahlsen, E., and Hyönä, J. (1994). A neurolinguistic analysis of morphological deficits in a Finnish-Swedish bilingual aphasic. *Clinical Linguistics & Phonetics*, 8(3):177–200.
- Lavric, A., Clapp, A., and Rastle, K. (2007). ERP evidence of morphological analysis from orthography: A masked priming study. *Cognitive Neuroscience, Journal of*, 19(5):866–877.

- Lavric, A., Elchlepp, H., and Rastle, K. (2012). Tracking hierarchical processing in morphological decomposition with brain potentials. *Journal of Experimental Psychology: Human Perception and Performance*, 38(4):811.
- Legge, G. E., Mansfield, J. S., and Chung, S. T. (2001). Psychophysics of reading: XX. Linking letter recognition to reading speed in central and peripheral vision. *Vision research*, 41(6):725–743.
- Lehtonen, M., Cunillera, T., Rodríguez-Fornells, A., Hultén, A., Tuomainen, J., and Laine, M. (2007). Recognition of morphologically complex words in Finnish: Evidence from event-related potentials. *Brain Research*, 1148:123–137.
- Lehtonen, M., Monahan, P. J., and Poeppel, D. (2011). Evidence for early morphological decomposition: combining masked priming with magnetoencephalography. *Journal of cognitive neuroscience*, 23(11):3366–3379.
- Leinonen, A., Grönholm-Nyman, P., Järvenpää, M., Söderholm, C., Lappi, O., Laine, M., and Krause, C. M. (2009). Neurocognitive processing of auditorily and visually presented inflected words and pseudowords: evidence from a morphologically rich language. *Brain research*, 1275:54–66.
- Leminen, A., Leminen, M., Lehtonen, M., Nevalainen, P., Ylinen, S., Kimppa, L., Sanemann, C., Mäkelä, J. P., and Kujala, T. (2011). Spatiotemporal dynamics of the processing of spoken inflected and derived words: a combined EEG and MEG study. *Frontiers in human neuroscience*, 5.
- Lenneberg, E. H. (1967). The biological foundations of language. *Hospital Practice*, 2(12):59–67.
- Lewis, M. P., Simons, G. F., Fennig, C. D., and others (2009). *Ethnologue: Languages of the world*, volume 16. SIL international Dallas, TX.

- Longtin, C.-M. and Meunier, F. (2005). Morphological decomposition in early visual word processing. *Journal of Memory and Language*, 53(1):26–41.
- Longtin, C.-M., Segui, J., and Hallé, P. A. (2003). Morphological priming without morphological relationship. *Language and cognitive processes*, 18(3):313–334.
- Luce, P. A. (1986). A computational analysis of uniqueness points in auditory word recognition. *Perception & Psychophysics*, 39(3):155–158.
- MacGregor, L. J., Pulvermüller, F., van Casteren, M., and Shtyrov, Y. (2012). Ultra-rapid access to words in the brain. *Nature Communications*, 3:711.
- Manelis, L. and Tharp, D. A. (1977). The processing of affixed words. *Memory & Cognition*, 5(6):690–695.
- Marslen-Wilson, W. and Warren, P. (1994). Levels of perceptual representation and process in lexical access: Words, phonemes, and features. *Psychological review*, 101(4):653–674.
- Marslen-Wilson, W. D. (1980). Speech understanding as a psychological process. In *Spoken language generation and understanding*, pages 39–67. Springer.
- Marslen-Wilson, W. D. and Welsh, A. (1978). Processing interactions and lexical access during word recognition in continuous speech. *Cognitive psychology*, 10(1):29–63.
- McCarthy, G. and Nobre, A. C. (1993). Modulation of semantic processing by spatial selective attention. *Electroencephalography and Clinical Neurophysiology/Evoked Potentials Section*, 88(3):210–219.
- McCarthy, J. J. (1979). *Formal problems in semitic phonology and morphology*. PhD thesis, MIT Cambridge, Mass.

- McCarthy, J. J. (1981). A prosodic theory of nonconcatenative morphology. *Linguistic inquiry*, pages 373–418.
- McCarthy, J. J. (1985). Formal problems in Semitic phonology and morphology.
- McClelland, J. L. and Elman, J. L. (1986). The TRACE model of speech perception. *Cognitive psychology*, 18(1):1–86.
- McClelland, J. L. and Rumelhart, D. E. (1981). An interactive activation model of context effects in letter perception: I. An account of basic findings. *Psychological review*, 88(5):375.
- Meunier, F. and Longtin, C.-M. (2007). Morphological decomposition and semantic integration in word processing. *Journal of Memory and Language*, 56(4):457–471.
- Meunier, F. and Segui, J. (1999). Frequency effects in auditory word recognition: The case of suffixed words. *Journal of Memory and Language*, 41(3):327–344.
- Midgley, K. J., Holcomb, P. J., and Grainger, J. (2009). Masked repetition and translation priming in second language learners: A window on the time-course of form and meaning activation using ERPs. *Psychophysiology*, 46(3):551–565.
- Münte, T. F., Say, T., Clahsen, H., Schiltz, K., and Kutas, M. (1999). Decomposition of morphologically complex words in English: Evidence from event-related brain potentials. *Cognitive Brain Research*, 7(3):241–253.
- Morgan, G. and Kegl, J. (2006). Nicaraguan sign language and theory of mind: The issue of critical periods and abilities. *Journal of Child Psychology and Psychiatry*, 47(8):811–819.
- Morton, J. (1964). A preliminary functional model for language behaviour. *International Audiology*, 3(2):216–225.

- Morton, J. (1968). *Grammar and computation in language behavior. CR1113 Progress Report No. VI.* University of Michigan.
- Morton, J. (1969). Interaction of information in word recognition. *Psychological review*, 76(2):165.
- Morton, J. (1979). Facilitation in word recognition: Experiments causing change in the logogen model. In *Processing of visible language*, pages 259–268. Springer.
- Muñoz, C. and Singleton, D. (2011). A critical review of age-related research on L2 ultimate attainment. *Language Teaching*, 44(1):1–35.
- Niemi, J., Laine, M., and Tuominen, J. (1994). Cognitive morphology in Finnish: Foundations of a new model. *Language and Cognitive Processes*, 9(3):423–446.
- Osterhout, L. and Holcomb, P. J. (1992). Event-related brain potentials elicited by syntactic anomaly. *Journal of memory and language*, 31(6):785–806.
- Paap, K. R. and Noel, R. W. (1991). Dual-route models of print to sound: Still a good horse race. *Psychological research*, 53(1):13–24.
- Papadopoulou, D. and Clahsen, H. (2003). Parsing strategies in L1 and L2 sentence processing: A study of relative clause attachment in Greek. *Studies in Second Language Acquisition*, 25(4):501–528.
- Peirce, J. W. (2007). PsychoPy—psychophysics software in Python. *Journal of neuroscience methods*, 162(1):8–13.
- Peirce, J. W. (2008). Generating stimuli for neuroscience using PsychoPy. *Frontiers in neuroinformatics*, 2.
- Penfield, W. (1959). Roberts. L. *Speech and brain mechanisms.*

- Perani, D., Paulesu, E., Galles, N. S., Dupoux, E., Dehaene, S., Bettinardi, V., Cappa, S. F., Fazio, F., and Mehler, J. (1998). The bilingual brain. Proficiency and age of acquisition of the second language. *Brain*, 121(10):1841–1852.
- Perea, M., abu Mallouh, R., and Carreiras, M. (2010). The search for an input-coding scheme: Transposed-letter priming in Arabic. *Psychonomic Bulletin & Review*, 17(3):375–380.
- Perea, M., Duñabeitia, J. A., and Carreiras, M. (2008). Transposed-letter priming effects for close versus distant transpositions. *Experimental Psychology*, 55(6):384–393.
- Perea, M., Gatt, A., Moret-Tatay, C., and Fabri, R. (2012). Are all Semitic languages immune to letter transpositions? The case of Maltese. *Psychonomic bulletin & review*, 19(5):942–947.
- Perea, M. and Lupker, S. J. (2004). Can CANISO activate CASINO? Transposed-letter similarity effects with nonadjacent letter positions. *Journal of Memory and Language*, 51(2):231–246.
- Perea, M., Lupker, S. J., Kinoshita, S., and Lupker, S. J. (2003). Transposed-letter confusability effects in masked form priming. *Masked priming: State of the art*, pages 97–120.
- Perea, M. and Pérez, E. (2009). Beyond alphabetic orthographies: The role of form and phonology in transposition effects in Katakana. *Language and Cognitive Processes*, 24(1):67–88.
- Perea, M. and Rosa, E. (2000). Repetition and form priming interact with neighborhood density at a brief stimulus onset asynchrony. *Psychonomic bulletin & review*, 7(4):668–677.
- Perfetti, C., Yang, C.-L., and Schmalhofer, F. (2008). Comprehension skill and word-to-text integration processes. *Applied Cognitive Psychology*, 22(3):303–318.

- Pinheiro, J., Bates, D., DebRoy, S., and Sarkar, D. (2009). The R Core Development Team. 2009. nlme: linear and nonlinear mixed effects models. *R package version*, 3:1–93.
- Plaut, D. C. (1997). Structure and function in the lexical system: Insights from distributed models of word reading and lexical decision. *Language and cognitive processes*, 12(5-6):765–806.
- Plaut, D. C., McClelland, J. L., Seidenberg, M. S., and Patterson, K. (1996). Understanding normal and impaired word reading: computational principles in quasi-regular domains. *Psychological review*, 103(1):56.
- Prince, A. and Smolensky, P. (1993). *Optimality Theory: Constraint interaction in generative grammar*. John Wiley & Sons.
- Radeau, M., Morais, J., Mousty, P., and Bertelson, P. (2000). The effect of speaking rate on the role of the uniqueness point in spoken word recognition. *Journal of Memory and Language*, 42(3):406–422.
- Radeau, M., Mousty, P., and Bertelson, P. (1989). The effect of the uniqueness point in spoken-word recognition. *Psychological Research*, 51(3):123–128.
- Raphael, L. J. (1972). Preceding vowel duration as a cue to the perception of the voicing characteristic of word-final consonants in American English. *The Journal of the Acoustical Society of America*, 51(4B):1296–1303.
- Rastle, K. and Davis, M. H. (2003). Reading morphologically complex words. *Masked priming: The state of the art*, pages 279–305.
- Rastle, K. and 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., and New, B. (2004). The broth in my brother's brothel: Morpho-orthographic segmentation in visual word recognition. *Psychonomic Bulletin & Review*, 11(6):1090–1098.
- Raveh, M. and Schiff, R. (2008). Visual and auditory morphological priming in adults with developmental dyslexia. *Scientific Studies of Reading*, 12(3):221–252.
- Recasens, D. (1991). An electropalatographic and acoustic study of consonant-to-vowel coarticulation. *Journal of Phonetics*, 19(2):177–192.
- Reicher, G. M. (1969). Perceptual recognition as a function of meaningfulness of stimulus material. *Journal of experimental psychology*, 81(2):275–280.
- Rumelhart, D. E. and McClelland, J. L. (1982). An interactive activation model of context effects in letter perception: II. The contextual enhancement effect and some tests and extensions of the model. *Psychological review*, 89(1):60.
- Sabourin, L., Brien, C., and Burkholder, M. (2014). The effect of age of L2 acquisition on the organization of the bilingual lexicon: Evidence from masked priming. *Bilingualism: Language and Cognition*, 17(03):542–555.
- Sabourin, L., Stowe, L. A., and De Haan, G. J. (2006). Transfer effects in learning a second language grammatical gender system. *Second Language Research*, 22(1):1–29.
- Samuel, A. G. (2001). Knowing a word affects the fundamental perception of the sounds within it. *Psychological Science*, 12(4):348–351.
- Schoonbaert, S. and Grainger, J. (2004). Letter position coding in printed word perception: Effects of repeated and transposed letters. *Language and Cognitive Processes*, 19(3):333–367.

- Schreuder, R. and BAAYEN, R. H. (1995). *Modeling morphological processing. Morphological aspects of language processing, ed. by Laurie B. Feldman, 131–54.* Hillsdale, NJ: Lawrence Erlbaum.
- Seidenberg, M. S. and McClelland, J. L. (1989). A distributed, developmental model of word recognition and naming. *Psychological review*, 96(4):523.
- Sáenz-Badillos, A. and Elwolde, J. (1996). *A history of the Hebrew language.* Cambridge University Press.
- Sereno, S. C., Rayner, K., and Posner, M. I. (1998). Establishing a time-line of word recognition: evidence from eye movements and event-related potentials. *Neuroreport*, 9(10):2195–2200.
- Silva, R. and Clahsen, H. (2008). Morphologically complex words in L1 and L2 processing: Evidence from masked priming experiments in English. *Bilingualism*, 11(2):245.
- Solomyak, O. and Marantz, A. (2010). Evidence for early morphological decomposition in visual word recognition. *Journal of Cognitive Neuroscience*, 22(9):2042–2057.
- Srinivasan, N. K. and Zahorik, P. (2012). Phonemic restoration effect reversed in a reverberant room. *The Journal of the Acoustical Society of America*, 131(1):EL28–EL34.
- Taft, M. (1979). Recognition of affixed words and the word frequency effect. *Memory & Cognition*, 7(4):263–272.
- Taft, M. (1981). Prefix stripping revisited. *Journal of verbal learning and verbal behavior*, 20(3):289–297.
- Taft, M. (1988). A morphological-decomposition model of lexical representation. *Linguistics*, 26(4):657–668.

- Taft, M. (2003). Morphological representation as a correlation between form and meaning. In *Reading complex words*, pages 113–137. Springer.
- Taft, M. (2004). Morphological decomposition and the reverse base frequency effect. *Quarterly Journal of Experimental Psychology Section A*, 57(4):745–765.
- Taft, M. and Forster, K. I. (1975). Lexical storage and retrieval of prefixed words. *Journal of verbal learning and verbal behavior*, 14(6):638–647.
- Taft, M. and Forster, K. I. (1976). Lexical storage and retrieval of polymorphemic and polysyllabic words. *Journal of Verbal Learning and Verbal Behavior*, 15(6):607–620.
- Taft, M., Hambly, G., and Kinoshita, S. (1986). Visual and auditory recognition of prefixed words. *The Quarterly Journal of Experimental Psychology*, 38(3):351–365.
- Tyler, L. K. (1984). The structure of the initial cohort: Evidence from gating. *Perception & Psychophysics*, 36(5):417–427.
- Ussishkin, A. (2005). A Fixed Prosodic Theory of Nonconcatenative Templatic morphology. *Natural Language & Linguistic Theory*, 23(1):169–218.
- Ussishkin, A. (2006). Semitic morphology: Root-based or word-based? *Morphology*, 16(1):37–40.
- Vartiainen, J., Aggujaro, S., Lehtonen, M., Hultén, A., Laine, M., and Salmelin, R. (2009). Neural dynamics of reading morphologically complex words. *Neuroimage*, 47(4):2064–2072.
- Velan, H. and Frost, R. (2007). Cambridge University versus Hebrew University: The impact of letter transposition on reading English and Hebrew. *Psychonomic Bulletin & Review*, 14(5):913–918.

- Velan, H. and Frost, R. (2009). Letter-transposition effects are not universal: The impact of transposing letters in Hebrew. *Journal of Memory and Language*, 61(3):285–302.
- Velan, H. and Frost, R. (2011). Words with and without internal structure: What determines the nature of orthographic and morphological processing? *Cognition*, 118(2):141–156.
- Versteegh, K. (1997). *20012. The Arabic language*. Edinburgh: Edinburgh University Press.
- Warren, R. M. and Sherman, G. L. (1974). Phonemic restorations based on subsequent context. *Attention, Perception, & Psychophysics*, 16(1):150–156.
- Whiting, C. M., Marslen-Wilson, W. D., and Shtyrov, Y. (2013). Neural dynamics of inflectional and derivational processing in spoken word comprehension: laterality and automaticity. *Frontiers in human neuroscience*, 7.
- Whitney, C. (2001). How the brain encodes the order of letters in a printed word: The SERIOL model and selective literature review. *Psychonomic Bulletin & Review*, 8(2):221–243.
- Whitney, C. and Cornelissen, P. (2008a). SERIOL reading. *Language and Cognitive Processes*, 23(1):143–164.
- Whitney, C. and Cornelissen, P. (2008b). SERIOL reading. *Language and Cognitive Processes*, 23(1):143–164.
- Whitney, C. and Lavidor, M. (2004). Why word length only matters in the left visual field. *Neuropsychologia*, 42(12):1680–1688.
- Whitney, C. and Marton, Y. (2013). The SERIOL2 Model of Orthographic Processing. *Online Submission*.

- Whitney, C. S., Berndt, R. S., and Reggia, J. A. (1996). Simulation of neurogenic reading disorders with a dual-route connectionist model. *Neural modeling of brain and cognitive disorders*, pages 201–228.
- William M. Schniedewind, a. (2013). *A social history of Hebrew: its origins through the Rabbinic period*. Anchor Yale Bible reference library. Yale University Press, New Haven.
- Winther Balling, L. and Harald Baayen, R. (2008). Morphological effects in auditory word recognition: Evidence from Danish. *Language and Cognitive Processes*, 23(7-8):1159–1190.
- Yu-Cheng Lin, Bangert, A. S., and Schwartz, A. I. (2015). The devil is in the details of hand movement. *Mental Lexicon*, 10(3):364–389.
- Zweig, E. and Pylkkänen, L. (2009). A visual M170 effect of morphological complexity. *Language and Cognitive Processes*, 24(3):412–439.