Diacritics and the Resolution of Ambiguity in Reading Arabic

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Abstract

The diacritical markers that represent most of the vowels in the Arabic orthography are typically omitted from written texts, thereby making many Arabic words phonologically and semantically ambiguous. Such words are known as heterophonic homographs and are associated with different pronunciations and meanings.

The aim of the six experiments reported in this thesis is to investigate how proficient readers of Arabic process diacritics, and how they understand heterophonic homographs with and without diacritics. In Experiment 1, readers were asked about the meaning of ambiguous and unambiguous words presented with and without diacritics. Results showed that diacritics improved the comprehension of ambiguous words (i.e., heterophonic homographs) without impacting their speed, but that they had no effect on the comprehension of unambiguous words while slowing them. Consistent results were observed in Experiment 2 where the materials comprised sentences rather than single words. Therefore, diacritics were found to improve reading comprehension by facilitating access to the semantic representations of heterophonic homographs that would otherwise be difficult to access from print. In Experiment 3, only the heterophonic homographs were diacritized in a sentence, in order to determine whether this selective diacritization might appear the most economic way to use diacritics. Even if mixed, the results suggested that adding diacritics to the whole sentence or to the heterophonic homograph only improved the comprehension of sentences equally. The results did not clearly provide evidence that selectively diacritizing the heterophonic homograph was optimal for reading comprehension. The last three experiments were conducted to further investigate how Arabic readers understand diacritized heterophonic homographs. The results suggested that even when diacritics were added to disambiguate a heterophonic homograph, it was still processed as if it was ambiguous and both of its meanings were activated.

Keywords: Arabic reading · Diacritics · Word recognition · Reading comprehension · Heterophonic homographs.

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1 GENERAL INTRODUCTION

Although Arabic is the native language of approximately 280 million people around the world, only a relatively small amount of scientific research has investigated the cognitive processes that are involved in reading the Arabic script. Nevertheless, there are several aspects of the Arabic writing system that distinguish it from European orthographies and make it particularly interesting to investigate. Most notably, in common with other Semitic scripts such as Hebrew, Arabic is primarily a consonantal system that provides vowel information by the use of small diacritic signs above or below the word. While diacritics add considerable phonological clarity to the words, they also significantly increase their visual complexity. In normal adult reading, vowels are omitted from the written script, and readers have therefore to rely on additional resources, such as context, to understand the written material.

In Arabic, if all the diacritics are presented, the orthography is phonologically transparent (i.e, shallow) in its orthography-phonology relations. If the vowel diacritics are missing, the print becomes phonologically more opaque/deep, with numerous ambiguous homographs. In this case, a word is considered phonologically *unambiguous* or homophonic if its undiacritized form has only one possible pronunciation when diacritized. In contrast, a word is considered phonologically *ambiguous* or heterophonic, when its undiacrtized form is associated with two or more phonological pronunciations when it is diacritized. Therefore, a single undiacritized printed word does not always signify its phonological form, as it can have two or more pronunciations with each pronunciation having a meaning (i.e., heterophonic homographs/heterophones). Approximately one in three words in a typical passage of text in Arabic is likely to be a phonologically ambiguous *heterophonic homograph* that has at least two different pronunciations associated with different meanings (e.g., a tear in English) (Abu-Rabia, 1997).

Because Arabic readers can read shallow and phonologically transparent diacritized script, as well as the more opaque undiacritized script, Arabic allows researchers the opportunity to examine the role of diacritics while minimizing individual differences. Such experiments in reading Arabic, may help clarify why it is that Arabic primarily uses a phonologically ambiguous script (i.e., undiacritized Arabic), even though it can draw on a much clearer one (i.e., diacritized Arabic).

Only a small amount of research has investigated the extent to which readers are affected by the presence or absence of diacritics in Arabic. There is evidence that diacritics improve accuracy but increase reading times. For instance, Bourisly, Haynes, Bourisly, and Mody (2013) found that diacritical markers slowed down lexical decisions about Arabic words regardless of word frequency. Abu-Leil, Share, and Ibrahim (2014) and Ibrahim (2013) showed that the presence of diacritics slowed down naming of written words. More recently, by monitoring eye-movements, Hermena et al. (2015) found evidence that diacritics could slow reading by adding visual complexity to the written script. Nevertheless, the work of Abu-Rabia (1996, 1998) revealed that the presence of diacritical markers increased the accuracy with which single words and paragraphs were read aloud by both skilled and less skilled readers of Arabic. Subsequently, he showed that diacritics improved the ability of school students to answer comprehension questions about passages (Abu-Rabia, 1999). Furthermore, Abu-Rabia (2001) indicated that both diacritical markers and sentence contexts improved accuracy and comprehension among skilled adult readers.

Although previous research (e.g., Abu-Rabia, 2002) has shown that the presence of diacritics generally facilitates comprehension of sentences and texts by adult readers of Arabic, it has not yet established precisely why and how this is the case. Also, even if more specific experimental research on Semitic word recognition (e.g., Koriat, 1985) has manipulated diacritics to assess the contribution of phonological information to reading, it has generally used tasks that do not require processing for meaning (e.g., lexical decisions and naming). But reading for meaning is of course essential to normal reading in everyday life. Therefore, this thesis will attempt to fill this knowledge gap by studying how Arabic readers process diacritics during reading comprehension, and how effectively they resolve the predominant phonological ambiguity they encounter in their everyday reading.

All the above-mentioned studies have certainly enriched our understanding of the Arabic-specific principles of reading, but they have also given us new insights into the universals of how phonologically ambiguous words are read. Indeed, experimental evidence from processing heterophonic homographs (e.g., *tear, wind*) in English (e.g., Folk and Morris, 1995) have already suggested that those words take significantly longer time to be read compared to unambiguous words, especially when they carry a subordinate meaning. However, while the pronunciation of a heterophonic homograph can be disambiguated only by a semantic context (e.g., by embedding it in a sentence) in English, an Arabic heterophonic homograph can be disambiguated by adding diacritics and still be presented as an isolated word. Therefore, Arabic can provide an additional point of reference to better understand how ambiguity is resolved in reading. It may serve as a valuable medium to further study the general effects of phonological ambiguity by specifying the exact pronunciation of the otherwise ambiguous written word.

The experiments that are reported in this thesis will investigate online semantic processing of diacritics and of heterophonic words in proficient Arabic adult readers by using semantic tasks. Because it allows the manipulation of phonological information by adding and removing vowel diacritics, Arabic gives us the unique opportunity to conduct within- and between- subjects experiments that compare readers' performance (in terms of latencies and error rates) in processing words and sentences with and without diacritics.

The first reported experiment was devised to determine whether diacritics facilitate or hinder the comprehension of written words. Its aim was to establish under which conditions diacritics impact on reading comprehension. Participants made decisions about whether a visually presented word had a living meaning. The key issue was whether readers process diacritics uniformly for all words, or if the effect of diacritic varies according to the words' characteristics (e.g., ambiguity, familiarity, dominance).

Since reading generally takes place in the context of sentence processing rather than single word processing, Experiment 2 examined how the words of Experiment 1 were understood when they were embedded in a sentence. The objective was to generalize the findings of the previous experiment by using an experimental task that would draw more closely on processes involved in normal reading.

Experiment 3 stemmed from the main findings of Experiment 1. Results had indicated that diacritics facilitated access to the meaning of ambiguous heterophonic words and slowed down access to the meaning of other unambiguous words. Thus, it seemed interesting to examine the question of whether there is an optimal diacritized condition that keeps reading at the same time as quick and as accurate as possible. The hypothesis is that the best condition for the reader might occur when only the ambiguous word is diacritized. That is because the ambiguous word would be better understood, without slowing down the rest of the sentence. The task in Experiment 3 was to say whether a sentence can be meaningful. The critical condition was a selectively diacriticized sentence in which only the ambiguous word was diacriticized, and the controls were the same sentences entirely diacriticized or undiacriticized.

Finally, the last three experiments were conducted to further investigate how Arabic readers process diacritized heterophonic homographs and therefore resolve phonological and semantic ambiguity while reading Arabic. The findings from Experiment 1 have already indicated that the meanings of heterophonic homographs were accessed more accurately when diacritized. In Experiment 4, the objective was to further investigate whether this phonologically and semantically disambiguated word (heterophonic homograph with diacritics) is processed like any other phonologically unambiguous word or not. That is, does this written word's orthography activate both alternatives that share its consonantal structure or only its own specified meaning? To this end, performance on a semantic task was compared between two types of diacritized heterophonic homographs, one that corresponds to two semantically unrelated words (living/non-living) taken from Experiment 1, and the other that correspond to two words with related meanings (non-living/non-living). If the effects of the alternative phonological version of the orthographic form are present on target words, then performance on words with related meanings should be better than performance on words with unrelated meanings.

Combined, the research reported in this thesis has the potential to provide a fuller picture of the contribution of diacritics to reading comprehension in Arabic. It can also enhance our understanding of the way phonologically ambiguous words (i.e., heterophonic homographs) are processed in reading whether they are presented with or without vowels.

2 THEORETICAL BACKGROUND

2.1 Introduction

The purpose of the following reported experiments is to expand the understanding of the cognitive processes involved in reading Arabic. More precisely, the aim of this thesis is to study the way phonologically ambiguous words are understood, and to simultaneously determine the role of phonologically disambiguating diacritics in reading Arabic. Unfortunately, little work has been previously done on both topics; the way diacritics impact on reading Arabic and the way ambiguity is resolved in Arabic. Therefore, in the following review of the literature, relevant research from studies conducted in Arabic as well as English and Hebrew will be examined. Studies in English will provide a theoretical framework (for general models of reading and for the resolution of ambiguity) in which the results will be discussed. Findings from studies using diacritics in Hebrew will be generalized to present additional evidence on the role of vowel diacritics in reading Arabic. Because it is a Semitic consonantal writing system with a root and pattern type of morphology, Arabic orthography has been consistently compared to the Hebrew orthography in the literature. As such, findings from studies in Hebrew have been used as evidence supporting experimental results from studies using Arabic. Based on the similarities between the two writing systems, the experimental evidence found for studies in Hebrew will also be reported to support the ideas underlying the experiments reported in this thesis. Indeed, as the key interest of this thesis is the use of vowel diacritics and their role in resolving ambiguity in reading Arabic, studies that address the issues of the role of vowel diacritics in reading are particularly relevant to the current investigations.

Thus, in the next literature review, the reader will be first introduced to some of the characteristic features of the Arabic writing system. Then, the two main components of this thesis will be examined: the studies of the impact of diacritics on reading and the pertinent ambiguity literature. Finally, relevant empirical evidence from Semitic languages will be analyzed along with more general theoretical propositions from cognitive models, to further clarify how Arabic readers are supposed to process their written script.

2.2 The Arabic Linguistic Environment

Arabic is the fifth most common spoken language in the world and its script is the second most widely used one after Roman. It is a primarily consonantal writing system characterized by distinguishing features that make it relevant to further investigations. Therefore, studying Arabic reading in addition to the more widely studied Indo-European languages should enrich our understanding of both the universal and the language-specific principles of reading.

2.2.1 The Orthographic Characteristics of Arabic

Arabic has a unicase alphabet in which the concepts of uppercase and lowercase do not exist, and it is written from right to left. More notably, the Arabic orthographic system is visually more complex than the English one. That is, several letters of the alphabet are represented by similar or identical structures that are distinguished only by the existence, location, and number of dots that do not have any intrinsic phonetic value by themselves. For instance, the Arabic letters representing /t/, /th/, and /b/ have the same base but are differentiated by adding or changing the number or location of the dots.

ث	ت	ب

Table 2.1: Examples of similar letters distinguished by the location of their dots.

Thirteen of the 28 Arabic letters include dots, which can be placed above or below letters. Some of these letters have one dot (e.g., ب /b/), while others have two (e.g., ي /j/) or three (e.g., /ʃ/ش). Sometimes, just one dot can distinguish between two or more words (e.g., جديد حديد / *ħadi:d/*, */dʒadi:d* /iron, new).

Additionally, some letters are represented by different shapes, depending on their placement in the word (word initial, medial, final, and when they follow a non-connecting letter). 22 of the 28 letters in the alphabet have four shapes each, and six have two shapes each (final and separate).

ـغ	ـغـ	غـ	غ

Table 2.2: Examples of the different forms of the same letter

2.2.2 Word Morphology in Arabic

Arabic orthography is based on its complex derivational morphology. Derivational morphology is characterized by the presence of roots and word patterns. Most words are derived by embedding a root (generally triliteral) into a morpho-phonological word pattern. The core meaning of the word is conveyed by the root that is mainly made of consonants, while the phonological pattern that can be either a sequence of vowels or a sequence of consonants and vowels, conveys word-class information. The roots and phonological patterns are abstract entities and only their joint combination forms specific words. For example the root *ktb* conveys the meaning of writing, when it is embedded in a pattern of a subject */-aː-i-/, k aːtib* it gives the meaning of writer, while if it is embedded in an object pattern /*ma*-- *uː*-//makt *uːb*/, it gives the meaning of written or of letter. The majority of words are therefore made of at least two morphemes, with none of the morphemes being themselves words. There are 15 frequent word patterns for verbs, and nine frequent word patterns for nouns in Arabic (Abd El-Minem, 1987; Al-Dahdah, 1989).

This morphological complexity is shared by Hebrew. Katz and Frost (1992) have suggested that the morphology of Semitic languages has directly influenced the development of their consonantal writing systems. That is, while Semitic orthographies are phonetically complex, they are morphologically constant. This phonological complexity coupled with a simpler morphology could not be contained in a single orthography. Therefore, Arabic and Hebrew have evolved as orthographies in which the morphology was preserved (i.e., roots embedded in the core word) at the expense of phonological completeness (i.e., vowels as generally omitted diacritic). Hence, their writing systems provide the reader with the most essential information in a word, (i.e., the root) by denoting in print the optimal amount of phonological information (i.e., consonantal structure of the word) without adding the redundant vowels. The Arabic root plays a similar role to some English stems (e.g., *heal* in *health*, *unhealthy, healing*, and *healthful*).

2.2.3 Diacritics and Vowels in Arabic

As previously noted, one salient aspect of Arabic is the partial phonological information found within the body of the word. In Arabic (as in Hebrew), words are written mainly as consonantal roots; letters represent usually consonants except three letters that signify both consonants and long vowels, /ا/, /a:/و /, / u: /, /ي/, / i: /. The three short vowels appear as diacritical marks of which two, /a/ and/u/, stand above and one, /i/, below the body of the word. Vowels can be doubled at the end of nouns and adjectives that are not in the definite form.

In addition to the diacritics for the short vowels there are four other diacritical reading signs:

- ‘skoon’ indicates that there is no short vowel to follow
- ‘shaddah’ indicates doubling of the letter
- ‘maddah’: written above the mixed letter /ا/indicates it’s a glottal stop with a long vowel ā
- ‘hamzah’ indicates a glottal stop.

In general, the transparency of the relation between spelling and phonology of different orthographies can be placed on a continuum according to a factor called orthographic depth (Katz & Feldman, 1981; Klima, 1972; Liberman, Liberman, Mattingly, & Shankweiler, 1980; Lukatela, Popadic, Ognjenovic, & Turvey, 1980). The orthographic depth of an alphabeticorthography indicates the degree to which letters map consistently onto sounds; it depends on how easy it is to predict the pronunciation of a word based on its spelling. By itself, diacritized Arabic is a shallow orthography that represents its phonology unequivocally following simple grapheme-phoneme correspondences, while undiacritized Arabic is a deep orthography that represents phonology in a more equivocal way. In diacritized Arabic the word’s phonological information is complete as vowels are represented as diacritics, while undiacritized Arabic does not represent vowels in general. Therefore, phonological information is incomplete, and the word’s pronunciation needs to be derived via semantic context by fluent readers. The implications of orthographic depth on reading will be discussed elsewhere in this thesis.

In the absence of diacritics, a written word can be phonologically ambiguous and often represents more than one word, each with a different pronunciation and meaning. Such letter strings or written words are known as heterophonic homographs. The diagram in Figure 2.1 represents an example of a heterophonic homograph in Arabic.

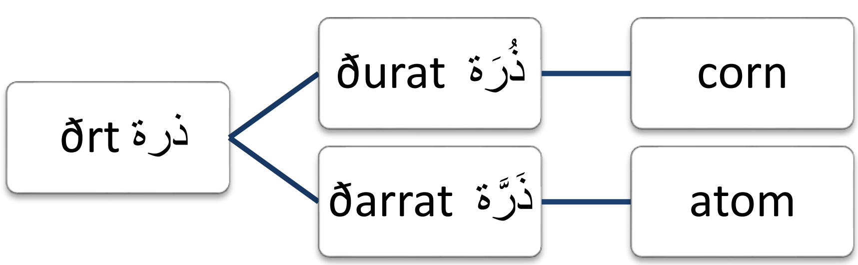

Figure 2.1: An example of heterophonic homograph in Arabic

Sometimes, the same string of letters could refer to up to eight phonologically and semantically different words. The homograph phenomenon is so common in Arabic that almost every third word in a passage can be a homograph (noun, verb, conjunction) representing several meanings with one version more common (dominant) than the others (subordinate) (e.g., Abu-Rabia, 1997). Hermena, Drieghe, Hellmuth and Liversedge (2015) indicated that the majority of Arabic ambiguous homographic words are biased homographs meaning that their versions are not equally common, and that they have a dominant and a subordinate meaning.

As a result of this homography phenomenon, the reader has to infer the appropriate pronunciation according to the context. For example, the sequence علم /*ʕlm*/ may be pronounced as /*ʕilm*/ ‘science’ or as /*ʕalam*/ ‘flag’ or as /*ʕalima*/ ‘he knew’ etc. As an illustration, homographs would appear to English readers as *sck* when presented without vowels and *sͥck*,*sͣck* or *sͦck* when diacritized.

Also, a typical sentence presents this way in Arabic without diacritics:

يحب الرجل أن يجلس قرب البحيرة تحت القمر

Its hypothetical equivalent English form could present this way:

Undiacritized: th mn lkes to st nr th lke ndr th mn

Diacritized: thͤ mͣn lͥkes tͦ sͥt nͤͣrͣ thͤ lͣke nͧdͤr thͤ mͦnͦ

Because the Arabic (or the Hebrew) reader needs to understand in order to read, the Semitic reading process seems to have reversed what is usually the norm in other languages, where people read in order to understand (Abu-Rabia, 1997). This likely stems from the ‘missing redundancy’ of Arabic (Hansen, 2014). That is, because of the lack of vowels, homography is widespread, thereby making decoding highly context-dependent. For instance, readers often need to overview the entire sentence before being able to read and understand the initial verb. So, Arabic is probably one of the few languages in which readers must first understand the gist of the text before reading it appropriately, and skilled readers of Arabic are likely highly proficient *because* they rely on context.

In everyday reading, the use of diacritics is typically restricted to primary school education. Diacritics are mainly used during a period of about four to six years in primary education to initiate the learner on how to read without them. The majority of printed material (besides children's books, poetry, and liturgical texts) in the Arab world does not include the vowel diacritical marks. A rare exception is when diacritics are added to a heterophone when the surrounding context (text) does not sufficiently disambiguate it as a subordinate version (Schultz, 2004).

Further, an additional role for diacritization is to indicate the grammatical function of the word within a sentence (Abu-Rabia, 2002). That is, in a written sentence, the ending of the word is diacritized according to its grammatical function, which requires advanced phonological and syntactic skills from the proficient reader. This role of diacritics is beyond the scope of this work, and it will not be addressed any further in this thesis.

2.2.4 The Diglossic Nature of the Arabic Language

Arabic native speakers are born in a linguistic context called diglossia in which the language is used in two different varieties (For a discussion, see Ferguson, 1959). The first one is literary Arabic or modern standard Arabic (MSA) that is taught in school in parallel with reading and writing. It is the official language of all Arab states, and it is used for formal verbal communication and in all written material. In contrast, spoken Arabic is used for ordinary speech, and it has no written form. As such, the spoken dialect in a particular region is the native language of speakers of Arabic within that region, while MSA can only be learned through formal education. Thus, an Arabic speaker who has not studied literary Arabic may not understand a literary text read to him because the two related forms of Arabic are different to a great extent. The source of their dissimilarity might be phonological (e.g., loss of diphthongs and inter-dental phonemes in Dialectal Arabic), morphological (e.g., loss of the dual and plural forms in Dialectal Arabic), or syntactical (e.g., loss of grammatical marks in Dialectal Arabic). This situation of diglossia creates a linguistic distance between the mother tongue that is used almost everywhere outside aof school, and the language taught at school. Therefore, it might hinder children's reading acquisition (Abu-Rabia & Taha, 2006; Al-Mannai & Everatt, 2005; Saiegh-Haddad, 2003, 2004).

2.3 The Role of Vowel Diacritics in Reading: Evidence from Arabic and Semitic Languages

As previously discussed, one of the central characteristics of Arabic orthography is the use of diacritics to convey vowel information in print. Investigations of the role of those diacritics in reading have used several different reading tasks. Some have used single word tasks (i.e., lexical decision, naming, and semantic decision) with and without primes (e.g., Bentin & Frost, 1987). Others have used offline reading aloud and silent reading comprehension of sentences, paragraphs and texts (e.g., Abu-Rabia, 1997, 1998, 1999, 2001). A limited number of studies have also used eye-tracking techniques (Roman & Pavard, 1987; Hermena et al., 2015, 2016) and neuro-imaging (Bourisly et al., 2013) in order to understand how diacritics are processed in print.

Studies of the role of diacritics in Semitic word recognition for developing and skilled readers showed mixed results. Diacritics either facilitate (Koriat, 1984, 1985; Navon & Shimron, 1981; Abu-Rabia, 1997), have no effect (e.g., Bentin and Frost, 1987), or hamper (Ibrahim, 2013; Roman and Pavrard, 1987) word recognition. The reasons for this inconsistency are not immediately clear; it might be that the demonstration of the effects of vowels on word recognition was dependent on experimental conditions that were highly variable among studies. For instance, the type of task (e.g., naming or lexical decision), the reading proficiency of the participants (e.g., skilled or developing), as well as the phonological ambiguity (e.g., heterophonic or homophonic), the frequencies of the target words (high-frequency or low-frequency) and the presence or absence of non-words in the experimental stimuli are influential variables that differed across investigations.

2.3.1 The Role of Diacritics in Experimental Tasks Using Single Words: Lexical Decisions, Naming, and Semantic Decisions.

2.3.1.1 Studies in Hebrew

Originally, many of the studies of the processing of vowel diacritics in reading Hebrew were designed to detect the relative contribution of phonological and orthographic processing to word recognition and reading. They aimed to investigate whether readers of Hebrew use assembled or addressed phonology in reading. More details on assembled vs. addressed phonology are found in section 5 of this chapter. In brief, assembled phonology is an indirect nonlexical/sublexical/pre-lexical reading route that the reader uses by translating letters to sounds according to the language's grapho-phonemic conversion rules (i.e., phonics) before accessing the word's lexical entry. Addressed phonology on the other hand, is a quicker post-lexical/lexical direct route that the readers can use to access the word's lexical entry directly from its printed form, and retrieve from that entry the word's pronunciation.

Because it allows the manipulation of phonemic information by using diacritized vs. undiacritized script, Hebrew (like Arabic) offers a unique way of investigating the extent to which readers rely on phonemic and/or orthographic codes while reading. By comparing the performance of the reader on a script that is phonologically ambiguous, to an equivalent script that is disambiguated by the use of additional diacritics, Hebrew and Arabic give researchers an original insight on the extent to which phonology is pre-lexical (assembled) or post-lexical (addressed) in reading, while minimizing the impact of individual differences.

The investigations of processing diacritized and nondiacritized single Hebrew words proposed that the effect of diacritics on word recognition is additionally modulated by the type of stimuli (i.e., heterophonic or homophonic, high-frequency or low-frequency) and by the demands of the experimental task (i.e. naming, lexical decision, and semantic categorization). Note that homophonic homographs have only one pronunciation when undiacritized (e.g., سيارة */sayyarat/ car*), while heterophonic homographs have more than one pronunciation when undiacritized (e.g., كتب can be sounded out as /*kataba/ he wrote* or */kutub/ books*). Overall, comparisons of latencies between diacritized and nondiacritized Hebrew words revealed a clear distinction between the pattern of responses to heterephonic homographs with two or more readings (such as tear in English), and the pattern of responses to phonologically unambiguous homophonic words with one reading. Additionally, the reported experimental data differed across tasks: responses to lexical decisions (LD) were different from those to naming and to semantic decision (SD). Of course, each one of these tasks entails a specific aspect of reading for accurate responses that might explain the inconsistent results between tasks. For instance, the recognition of the orthographic form as a word is sufficient to accomplish a correct decision in LD, whereas naming requires a phonological alternative to be determined, and SD requires a specific meaning to be activated so that a correct decision is made.

In summary, the data relative to unambiguous homophonic homographs suggested that adding vowels did not impact LDs for high-frequency (Navon & Shimron, 1985; Koriat, 1985; Bentin & Frost, 1987; Frost, 1994) and low-frequency (Bentin & Frost, 1987; Frost, 1994) words. Latencies to SDs were found to be similar between diacritized and undiacritized words (Navon & Shimron, 1985). Naming of unambiguous homophonic words was however clearly facilitated by the presence of diacritics (Navon & Shimron, 1982; Koriat, 1984, 1985; Frost, 1994). In opposition, a totally different pattern of responses emerged for ambiguous heterophonic homographs: adding vowels delayed both lexical decisions for all words and naming for low-frequency (subordinate) words, but it did not affect naming of high-frequency (dominant) heterophones (Bentin & Frost, 1987). The observed pattern of results was thought to reflect the different reading strategies adopted by Hebrew readers when reading the diacritized vs. the undiacritized script. The details of the relevant studies will be reviewed below, and their interpretation in the context of more general models of processing Semitic orthographies will be explained in subsequent paragraphs.

The impact of diacritization and therefore of phonological processing was investigated in Navon and Shimron's studies (1981, 1982, 1985) by measuring the time course of naming unambiguous (i.e, words with one reading/homophonic) diacritized and undiacritized Hebrew words. Navon and Shimron (1981, 1982) examined whether developing and proficient readers can focus on only the orthographic form of a word (the written word) while ignoring its phonological recoding (the word and its diacritics). The words used were homophonic so that their vowels could be considered as redundant and lexically uninformative. Naming latencies for four types of stimuli were compared (diacritized words; undiacritized words; words printed with irregular diacritization, either wrong signs that preserve phonological value or wrong signs that do not preserve phonological value). The authors' primary aim was to learn whether the grapheme-to-phoneme translation of a written word is automatic regardless of its role in lexical access, and whether phonemic access is pre-lexical or post-lexical in word recognition. If it is pre-lexical (assembled phonology), it is generated by phonologically recoding the graphemes before accessing the word. If it is post-lexical (addressed phonology), the phonological form of the word is retrieved from the visual/graphemic representation of the word in memory. If a reader cannot avoid recoding vowels signs, s/he will be sensitive to the interference of incorrect diacritization. In the experiments, participants were instructed to disregard the vowel signs when naming the word aloud. Results indicated that naming was equally fast for undiacritized and correctly diacritized words, as well as for incorrect ones that preserved the word sound, but that it was slower when the vowel signs were incompatible with the word sound. The instruction to ignore vowels was then eliminated and naming became quicker for diacritized words in this condition.

This sensitivity to phonemic distortion, coupled with insensitivity to both the elimination of vowels and graphemic distortion, led the authors to conclude that even when diacritics require extra visual processing and do not deliver any additional phonological information, they still facilitate reading aloud of unambiguous words. What is more, even if vowels are redundant and are not needed in naming unambiguous words, proficient readers cannot disregard them.

In a later study, Navon & Shimron (1985) tested those hypotheses with two additional experimental tasks, lexical decision and semantic decision. In the SD task, participants were presented with a category title then a target word; they had to decide whether or not the word belonged to the category just presented. In SD and LDs, no difference emerged between latencies for correctly diacritized and undiacritized words. There was a small, nonsignificant difference between correctly diacritized and graphemically distorted words. A large significant difference was found between correctly diacritized and phonemically distorted words. Therefore, the authors assumed that while readers were not affected by the elimination of diacritics, they were only slightly affected by graphemic/visual distortion, but clearly disturbed by phonemic distortion. Of note, although the pattern of responses was similar across tasks, the results for the semantic decision task were weaker than those for naming and lexical decision.

Koriat (1984, 1985) found a facilitating effect of diacritics for more or less frequent homophonic words in naming. Stimuli were unambiguous words, either diacritized or undiacritized, and they were preceded by either semantically related or unrelated primes. In addition to the effects of diacritics, the effects of context and of word length were investigated. Koriat hypothesized that a context relevant to the given word should resolve phonological ambiguity, thus eliminating the effect of vowel diacritics. Also, the longer the letter string, the greater the advantage of diacritization should be. The result varied depending on the task and on the frequency of the word. In LDs and when frequent words were used, only context yielded a significant main effect, and there was no effect for diacritization or word length. The interactions between diacritics and either word length or context were nonsignificant. Conversely, when both high-frequency and low-frequency words were used, diacritization facilitated the recognition of low-frequency words but its effects were weaker for high-frequency words. Context significantly reduced the effect of vowels, but did not eliminate it, and the effect of vowels did not increase with word length. On the other hand, both diacritization and context facilitated naming. The interactions between diacritization and either word length or context were not significant.

Based on these mixed results, Koriat concluded that word frequency impacts the choice of the mediating process in lexical decision, the phonological mediation being involved to a greater extent in the recognition of low-frequency words. Because the word list contained a mix of low- and high-frequency words, participants tended to use the appropriate strategy for low-frequency words with both types of words. Contrary to the initial hypothesis, phonological mediation appeared to be carried out at once on the whole word. Furthermore, the effect of context was additive to the effect of diacritization, meaning that context shortened reading time for both diacritized and undiacritized words, contrary to the expectation that the facilitating effect of vowels should disappear when contextual hints are provided.

Some of these results were replicated in a study by Frost (1994) that examined the effects of lexical status (word vs. non-word) and frequency (high-frequency vs. low-frequency) in lexical decisions and naming of diacritized and undiacrictized unambiguous homophonic words with and without primes. Adding disambiguating diacritics did not clearly impact recognition of both low- and high- frequency words in LDs, while naming was improved for diacritized words in comparison to undiacritized ones. Additionally, the results indicated that response times in naming and in lexical decision were significantly more similar in the undiacritized than in the diacritized condition. That is, RTs in the two tasks were highly correlated when words were presented without diacritics, but much less so in the diacritized presentation. In naming, the effects of lexical status and of frequency were stronger in undiacritized than in diacritized print. All these results were interpreted as converging evidence supporting the claim that the readers were more likely to use addressed sub-lexical phonology when words were undiacritized, whereas assembled phonology was more likely to be used when vowels were added to the word. Moreover, Frost (1994) examined the effects of semantic facilitation in naming unambiguous words by using a semantic priming paradigm. Again, consistent with the findings of Navon and Shimron (1982) and of Koriat (1984), naming diacritized words was found to be faster than naming undiacritized words.

In contrast, other researchers did not find a major facilitating effect of Hebrew diacritics using lexical decision and naming of both unambiguous and ambiguous words (e.g., Bentin & Frost, 1987). These authors argued that, in Hebrew, lexical decisions are based on the orthographic codes rather than phonological ones, unless the attention of the reader is directed to the phonemic code by using diacritics. In other words, if a word is diacritized, lexical access is mainly mediated by phonemic codes, but if it is undiacritized, orthographic codes are predominant.

In one study (Bentin & Frost, 1987), unbalanced ambiguous heterophones (corresponding to two words if diacritized, one of high frequency, and one of low frequency) and unambiguous Hebrew words were compared in their undiacritized and diacritized forms in both lexical decision and naming. Results suggested that lexical decision was faster for the ambiguous undiacritized words than for any of its disambiguated diacritized alternatives. For unambiguous homophonic words on the other hand, no differences between latencies for diacritized vs. undiacritized words was found. These findings were claimed to support the possibility that lexical decision for heterophonic words was based on the abstract orthographic representation of the word (the word without diacritics), which is common to all its phonological alternatives (the two diacritized versions of the word), without any need for additional resolution of phonological ambiguity to take place (For a discussion, see section 5.2 in this chapter). In the naming task, results showed that unambiguous words were named at the same speed whether they were diacritized or not. The high frequency alternative of ambiguous words was read aloud as quickly as its undiacritized form, while the low-frequency alternative was named significantly slower. Vowel marks were therefore thought to impede naming when they imposed a less familiar pronunciation. The authors concluded that based solely on the consonantal information, readers might initially activate the most frequent (in the case of ambiguous words) or the only (in the case of unambiguous words) alternative. The addition of diacritics was thought not to have any effect on the processing time if diacritics match the reader's initial response tendency. Otherwise, in the less frequent condition, diacritics delay the processing of written words by requiring a time-consuming revision of the output.

In the previous experiments on the lexical disambiguation of heterophonic Hebrew homographs, participants mainly expressed the more frequent of two alternatives when naming the undiacritized version of these words. However, it was not clear whether their lexical access followed a parallel-access model (Onifer & Swinney, 1981; Seidenberg, Tanenhaus, Leiman, & Bienkowski, 1982) or an ordered-access model (Forster & Bednall, 1976; Hogaboam & Perfetti, 1975; Simpson, 1981) in such a case. As it will be explained elsewhere in this thesis, in a parallel-access model, all possible meanings of the homograph are automatically activated in parallel during lexical access, while in an ordered-access model, the dominant meaning of a homograph is retrieved first. Therefore, a more direct measure was necessary to examine whether more than one meaning of a an ambiguous word is automatically activated during the disambiguation process, and whether this access is ordered by the relative frequency of each meaning.

Frost & Bentin (1992) investigated the time-course of activating the more or less frequent homograph by having participants perform primed LDs after a delay. Participants were asked to perform a lexical decision in which targets followed primes at three stimulus onset asynchronies (SOAs 100 ms, 250 ms, and 750 ms). Primes were heterophonic words that could have two meanings, one dominant (i.e., high-frequency) and one subordinate (i.e., low-frequency) if diacritized. Targets could be unrelated to the prime, or they could be related to the dominant or to the subordinate alternative of the prime. Two experiments were conducted; one in a fully undiacritized condition, and the other in a fully diacritized condition. Results indicated that in the undiacritized condition, lexical decisions for targets related to the dominant phonological alternatives of the ambiguous primes were facilitated (shorter RTs at all SOAs), while targets related to the subordinate alternatives were facilitated only at SOAs of 250 ms or longer. These results were believed to be consistent with the prediction that the meanings of an undiacritized heterophonic homograph are retrieved by an ordered-access model, the dominant meaning of the word being accessed before its subordinate alternative. Conversely, in the diacritized condition priming facilitated lexical decision to targets at all SOAs regardless of the dominance of the meaning to which the targets were related, suggesting that the time-course of processing high and low-frequency disambiguated words is similar. In the ambiguous undiacritized condition, in the absence of phonological ambiguity, both the dominant and the subordinate meanings were available at 100 ms from stimuli onset and they remained active till 750 ms.

The authors discussed the results with regard to models of disambiguating phonologically and semantically ambiguous words in Hebrew. They suggested that that at least two meanings for each heterophonic homograph are retrieved during lexical access. However, the time course of activating the different meanings and the amount of activation was related to the extent of the phonological ambiguity of the word. In addition, the process of disambiguating a word that is both phonologically and semantically ambiguous (i.e., undiacritized heterophonic homograph) is different from the process of disambiguating a word that is only semantically ambiguous (diacritized heterophonic homograph, and homophonic homograph). The details of the proposed models will be discussed in paragraph 2. 5. 2.

2.3.1.2 Studies in Arabic

Similarly to findings from Bentin and Frost (1987), experimental evidence from Arabic suggests that diacritics may delay word recognition at least in lexical decisions (Bourisly et al., 2013) and naming (Ibrahim, 2013). A number of recent studies tried to speculate on the reasons why this is the case (Abu-Rabia, 2012; Ibrahim, 2013; Hermena et al., 2016). One of the possible explanations is that the hindering effect of adding vowel diacritics may reflect the lack of familiarity of the reader with the diacrized script in his or her everyday reading. Also, diacritizing a word may add in visual complexity to its processing leading to an additional cost in recognition time. Moreover, diacritized script may direct the readers' attention to phonology, thereby leading them to use a slower assembly route in reading as compared to the more efficient lexical route (for more details about the dual-routes of reading, see section 5.1.2 in this chapter). At this stage, all these attempted explanations are still speculative, but they can nevertheless shed additional light on the reasons behind the observed effects of diacritics in reading Arabic script. A number of relevant studies will be reviewed below.

Roman and Pavard (1987) investigated lexical decisions in Arabic by using diacritized and undiacritized heterophonic words with skilled readers. The diacritized version of the words was dominant. Results showed that vowel diacritics significantly slowed lexical decisions. The researchers concluded that the addition of phonologically disambiguating diacritics inhibits rather than facilitates lexical decision in Arabic.

Similarly, Bourisly et al. (2013) did not find a significant main effect for vowel diactrics on accuracy measures in LD for either high- or low-frequency words, but found significantly shorter reaction times for undiacritized words regardless of their frequency. This suggests that readers recognize diacritized words as accurately as undiacritized words but they take significantly more time in doing so. Importantly, no effect of diacritics was found with non-words.

Ibrahim (2013) found again that diacritics hampered naming words (both in terms of accuracy and reading times) in developing readers. Naming of diacritized and undiacritized words, as well as diacritized pseudo-words was investigated with developing readers in 8th grade. Participants were asked to read aloud diacritized words, undiacritized words, and non-words. Results indicated that the participants were slowest in reading pseudo-words and fastest in reading undiacritized words, with diacritized words falling in between. Reading accuracy measures revealed the same pattern of responses. The hampering effects of vowels were interpreted as adding visual complexity to words that are usually read without vowels. The 8th grade reader is generally used to reading undiacritized but not diacritized print through an orthographic strategy in which the undiacritized words that do not contain all the phonological information can be recognized directly in their visual-orthographic form, rather than indirectly by recoding their phonology (Taouk & Coltheart, 2004). The addition of the unfamiliar vowels diacritics was thought to direct the reader to phonological information and therefore to hinder fluent reading by leading the developing reader to use a less efficient indirect route instead of the more familiar and usual direct route.

Abu-Leil et al. (2014) replicated the hampering effects of diacritics on naming in 8th graders. Participants were presented with diacritized non-words, as well as diacritized and undiacritized words in a naming task. Both accuracy and speed were measured. Results showed that readers were slowest and least accurate when reading pseudowords, and fastest and most accurate when reading undiacritized words. Diacritized word fell in the middle between pseudo-words and undiacritized words. The same pattern was found in naming accuracy. This surprising result was again explained by the lack of familiarity with the fully diacritized condition. Students in 8th grade have not had the opportunity to encounter diacritized script since the 4th grade. They, therefore, no longer attempt phonological recoding, which would be helped by diacritization, and instead adopt orthographic whole-word encoding which is necessary for processing the phonologically incomplete undiacritized script. The experimental condition in this study led the readers to use the less familiar and less efficient phonological codes instead of the more used orthographic codes.

2.3.2 The Role of Vowels in Reading Arabic Words in Context: Sentences, Paragraphs and Texts

In addition to the experimental tasks on the time-course of single word-recognition, several studies (chiefly by Abu-Rabia and his collaborators) investigated more specifically the effect of vowels on reading sentences and texts in Arabic (in addition to word reading) for developing and skilled readers. Their findings concurred that short vowels play two roles in Arabic for developing as well as skilled readers: One indispensable role in facilitating reading accuracy of single words, and another additive role in both reading accuracy and comprehension of sentences and texts.

Of note, accuracy when reading aloud can be defined in two ways in Arabic. A conservative definition includes the diacritization of the end of the word in considering reading as accurate, and a less stringent one does not include the final vowel in examining reading accuracy (as it does not change the meaning of the word). As reported in the previous paragraphs, diacritization serves two purposes: the first and essential one is to give phonological information on how to pronounce the written word; it involves all the vowel diacritics in the word, but not the one posted on the final letter. The second one is used to indicate the grammatical function of the word in the sentence; it is based on the diacritic that is posted on the final letter. Where appropriate, the definition of the used reading accuracy will be specified in the following experiments.

2.3.2.1 Offline Studies

In a study by Abu-Rabia (2012), the role of phonology (diacritization) and morphology (roots) in reading morphologically complex words in sentences was studied among skilled adult Arabic readers. The participants were asked to read aloud diacritized and undiacritized words and sentences. The sentences contained a target word preceded or not by its root. The results showed that both diacritization and roots facilitated reading accuracy of morphologically complex words in adult skilled readers. Words were read most accurately when they were in a diacritized sentence with a priming root. The second best reading condition was when the words were in an undiacritized sentence with a root. The poorest accuracy results were when the word was undiacritized and isolated. The result that diacritization facilitates reading of single words as well as words in a sentence accords with many previous studies by Abu- Rabia (e.g., Abu-Rabia, 2001). It suggests that, unlike in other orthographies such as English where phonology is most important in the first stage in reading and writing, the use of phonology accompanies readers throughout their life in Arabic (also see, Abu-Rabia & Taha, 2004, 2006).

Another study by Abu-Rabia (2001) investigated the influence of diacritization and context on both reading accuracy and reading comprehension among adult native Arabic skilled readers. The aim the study was to clarify the relationship between reading accuracy and reading comprehension as a function of vowels. The stimuli consisted of words, paragraphs, and texts presented in two conditions, diacritized and undiacritized. Participants were asked to read aloud a list of single words and a paragraph. They were also requested to read silently a short story and to answer multiple-choice comprehension questions. Again, the story and the questions were presented in a fully diacritized and in an undiacritized condition. The participants were tested for reading accuracy and for reading comprehension. The results suggested that vowels and context improve accuracy and comprehension across all reading conditions. Sentence context in the fully diacritized paragraphs did not impact reading accuracy when compared to the fully diacritized words, but context improved reading accuracy in the undiacritized condition. Reading comprehension results did not positively correlate with the reading accuracy results, and reading accuracy scores did not predict reading comprehension.

These findings suggest that in Arabic, reading aloud is a different process from silent reading comprehension. For reading aloud, vowels and context are essential facilitating factors: vowels supply phonological information, which makes accurate reading aloud easier, and context provides additional disambiguating semantic information. For silent reading comprehension on the other hand, diacritization helps in ambiguous situations to save time and cognitive effort: with undiacritized texts, the reader's cognitive effort is focused at the same time on morphological recognition of words for lexical access and on a top-down process for bridging semantic gaps. Through this interaction, the general knowledge of the reader compensates for the lack of phonological information and comprehension is promoted by semantic guessing. In contrast, in the fully diacritized text, the semantics are clear and needed less cognitive effort such as semantic guessing or use of prior knowledge for word recognition; as a result, the major cognitive effort of the reader is allocated to text comprehension.

These results confirm previous findings by Abu-Rabia with skilled and poor readers in the 10^{th} grade. For instance, Abu-Rabia investigated the effect of vowels and context on reading accuracy of words and of paragraphs in poor and skilled 10^{th} graders (Abu-Rabia, 1997). Two levels of readers, poor and skilled were tested in four reading conditions, diacritized, undiacritized, texts and words. The isolated words were considered correct if they were accurately read, regardless of the final letter diacritization, while the words within the text had to be read accurately with full diacritization to be considered correct. The results revealed that there was a main effect for reading level, context, and diacritization. There was also an interaction between reader/context, reader/vowels, context/vowel, and reader/context/diacritization. This indicates that context and/or diacritization helped poor and skilled readers, but that skilled readers benefited more from it. Reading undiacritized isolated words was found problematic even for skilled readers as both skilled and poor readers failed when they read isolated undiacritized words. Adding vowels and/or putting the words in a text improved reading accuracy in both poor and skilled readers. Abu-Rabia interpreted the results within the framework of reading theories. He argued for a distinction between diacritized and undiacritized Arabic, in context or out of context. The reading process in Arabic was claimed to be an interactive process of context and word recognition. Vowels contribute to reading by adding phonological information to word recognition and disambiguating homographs. Moreover, the sentence context contributes by adding semantic priming for disambiguating homographs, specifically when vowels are not presented. When reading a text, readers compensate for the absence of vowels by relying on context. Therefore, context and vowels were found to be important in reading accuracy regardless of reading level. In Arabic, readers must first understand the sentence to recognize the word, which is very hard for the poor reader, but more manageable by the skilled reader.

Similarly, in another study (Abu-Rabia, 1998) the effect of vowels on reading accuracy in different text types (narrative, informative, poetic, and Koranic) in skilled and unskilled native Arabic speakers was studied. The participants were native Arabic readers aged 17, divided into two groups, poor and skilled. They were presented with four kinds of text: narrative, informative, poetic, and Koranic. In each kind of text, three different texts were presented in three different conditions: diacritized, undiacritized, and incorrectly diacritized. In the incorrectly diacritized condition, vowel diacritics were posted on the wrong letter, making the word either a different one, or a pseudo-word. The participants were tested for reading accuracy. There was a significant main effect of vowels and of reading levels across text types, and there was an interaction between readers and vowels. Results showed that both poor and skilled readers improved their reading accuracy when they read with vowels, but that the skilled readers benefited more than the poor readers from the contribution of vowels. Additionally, poor and skilled readers did not ignore vowels when they were wrongly posted on letters, which led to wrong pronunciation. Based on the results, it was evident that vowels facilitate word recognition even when words are in context for both poor and skilled readers.

Context was further investigated by the same author (Abu-Rabia & Siegel, 1995) to study how native Arabic eighth-graders read diacritized and undiacritized words with and without context. The purpose of the study was to determine if Arabic readers rely more on context than skilled readers, as was found in English orthography (e.g., Perfetti, 1985; Stanovich, 1980, 1986). The participants were native Arabic readers aged 15. They were divided in two groups of skilled and poor readers. They were presented with 20 sentences, half diacritized and half undiacritized. The first word of each sentence was a phonologically and semantically ambiguous word when undiacritized. The participants were asked to read the first word of the sentence while the rest of the sentence is hidden. Then, they were shown the rest of the sentence and asked to read it aloud. The results indicated that there were main effects of reading level, diacritization, and context on word reading accuracy. There was also a significant interaction between reading level/context and reading level/context/diacritization, but there was no effect of reading level and diacritization. Namely, skilled and poor readers read better with vowels and with context, but reading undiacritized ambiguous isolated words did not showany difference between skilled and poor readers and was very difficult for both. Additionally, skilled readers relied more on context and on diacritization to read accurately. These findings suggested again, that Arabic reading consists of a combination of word recognition and context effects in both skilled and poor readers, unlike in English reading, where poor readers rely more on context than skilled readers (Bruck, 1990; Perfetti, 1985; Simpson & Foster, 1986; Stanovich, 1980, 1986; Stanovich & Feedman, 1981). Both skilled and poor readers rely on context in reading diacritized and undiacritized words in Arabic. They also fail to read words correctly without vowels and without context; typically, they read them as the most frequent and common word in Arabic.

More recently, Abu-Leil et al. (2014) replicated the facilitating effect of diacritics on the ability of skilled 8th graders to answer comprehension questions about short passages of text. Readers were presented with diacritized and undiacritized texts and their corresponding questions. Readers understood diacritized texts better than undiacritized ones, despite the fact that oral word reading was slower and less accurate for diacritized than undiacritized words. Further, consistent with Abu-Rabia's results (2001), reading comprehension did not strongly correlate with reading fluency and reading accuracy scores, indicating that silent reading comprehension is largely unrelated to reading aloud in Arabic both in terms of accuracy and speed. Based on this pattern of results, the authors argued that vowels have a dual function: one that helps phonological decoding and is important to reading aloud. In this situation, diacritics facilitate beginning reading, but become a hindrance to older readers who are no longer familiar with them but cannot ignore them. The other function helps meaning determination by disambiguating homographs and therefore is essential to reading comprehension.

2.3.2.2 Eye-Tracking Studies

In addition to offline studies of reading sentences, texts and paragraphs, a few eye-tracking investigations gave additional information on processing diacritics in sentences, paragraphs and texts. Roman and Pavard (1987) conducted the first eye-movement studies on diacritized and undiacritized Arabic texts. Findings showed that vowel diacritics significantly hindered reading by reducing reading speed and significantly increasing the number of fixations and fixation duration. The authors attributed these slowing effects of diacritics to two reasons. One is an increase *in perceptual noise* or *visual crowding*, which is the interference between the added diacritics and the surrounding letters.

Hermena et al. (2015) further investigated the processing of diacritics that disambiguate heterophonic homographic verbs as either active or passive. The objective of their explorations was to shed light on whether or not diacritics are processed automatically during normal text reading and on whether or not the mode of the diacritization (diacritics only on critical heterophonic homographs vs. fully diacritized text) affect the manner in which text is processed during normal reading. To this end, they used verbs that are heterophonic homographs in their active and passive voice. That is, the same undiacritized string of letters referred to two different pronunciations, one for the active voice of the verb and one for the passive voice of the word. Each of these verbs was embedded in stimuli sentences under five conditions (non diacritized; fully diacritized with active meaning; partially diacritized (only heterophonic verb diacritized) with active meaning; fully diacritized with passive meaning; partially diacritized (only heterophonic verb diacritized) with passive meaning).

The findings revealed that the verb was skipped significantly more in the non diacritized condition, but no difference was found between the two diacritized conditions (verb only vs. full sentence), indicating that the reader is sensitive to the presence of diacritics on a word before reading it, which increases the likelihood of it being fixated, regardless of whether the verb or the whole sentence is diacriticized.

Hermena et al. also found that readers benefited from diacritics in the condition where only the heterophonic verb was diacritized. Otherwise, when diacritics were added to all words in the passive sentence, readers failed to make use of the disambiguating diacritics on the verb to the same degree that they did when diacritics were added only to this heterophonic verb for disambiguation. This suggests that skilled readers may not automatically process (mostly redundant) full sentence diacritics, but instead they likely rely on context to disambiguate heterophonic homographs.

Additionally, in the absence of diacritics, readers followed their preference for simple active analysis of ambiguous verbs: Readers read the verb as active until they reach a disambiguating context, and garden path effects were found. These effects manifest as a disruption in processing when the reader reaches a disambiguating region in the sentence that helps him/her detect their initial misananlysis.

Moreover, adding full diacritics to the active sentences reliably increased the average fixation duration by a small 6 ms. as compared to the undiacritized condition. However, sentence reading times were similar between the two conditions, because of a counterbalancing small nonreliable decrease in the number of fixations in the fully diacritized condition. The authors suspected that this small increase in fixation duration may be due to visual crowding, in which adding visual information in the form of diacritics slows the readers' visual processing of stimuli. This effect of visual crowding on fixation duration is well documented in other languages, especially in English (e.g., Liversedge et al., 2014; Slattery & Rayner, 2013). The authors did not however eliminate the possibility that this small fixation duration increase might reflect a lack of familiarity of Arabic readers with the fully diacritized sentences. Therefore they took the trial number into account when interpreting results to determine whether readers' performance with fully diacritized sentences changed as they encountered more examples of such sentences throughout the experiment. They did not report any change in the readers' performance across time.

In a subsequent follow-up study, Hermena, Liversedge, and Drieghe (2016) aimed to expand the finding that readers are sensitive to the presence of diacritics in the parafoveaby establishing whether they truly identify the diacritics parafoveally, besides being sensitive to their presence. More particularly, their objective was to determine which variables might influence the processing of diacritics. For this purpose, they investigated the way readers pre-process Arabic diacritics in the upcoming words by using the boundary paradigm in which the readers see a different display depending on where they are looking. The readers were presented with either diacritized or undiacritized sentences containing heterophonic homographs. The undiacritized sentences did not completely disambiguate whether the dominant or the subordinate version of the homograph was present, thus making the use of diacritic non redundant and ecologically valid. The target homographs were given diacritics of either dominant or subordinate pronunciations, and they were present with three different previews (undiacritized; identical diacritization; opposite diacritization such that if a target has the dominant diacritics then the preview has the subordinate ones and vice versa).

The results indicated that opposite previews inflated initial fixation durations on the target word, which suggest that diacritics are identified parafoveally (at close launch site). Additionally, when the parafoveal preview of the diacritics did not allow for their presence to be detected (at far launch site), readers expected to see the dominant heterophone, and therefore when the subordinate diacritics were present instead, gaze duration was inflated. In addition, identical previews of the diacritics (at close launch site), benefited only the subordinate pattern and not the dominant one. The authors interpreted this result as evidence of how the reader's expectations (for the subordinate diacritization pattern) modulate processing of the upcoming diacritics. As reported in chapter 3, printed diacritization usually directs the reader toward the subordinate meaning when the context does not disambiguate the word, while the dominant pronunciation is typically left undiacritized. Hence, when diacritics are perceived by the reader, they are expected to belong to the subordinate meaning. This expectation later modulates processing of the diacritics such that identical preview benefits only the expected subordinate diacritization pattern.

The findings of this experiment were all summarized as a series of interacting variables in processing diacritics: The pattern of diacritization present on the target word (dominant or subordinate), the type of preview available to the readers prior to fixating the diacritized word (identical or opposite), the quality of the preview available of the diacritics (undetected at far launch site or identified at close launch site), and the readers' expectations for a particular pattern of diacritics (dominant or subordinate) were all found to contribute to processing diacritics in print.

2.4 The Resolution of Ambiguity in Word Recognition and Reading: Evidence from Studies in English

Diacritics typically contribute to reading Arabic by giving additional phonological information to an otherwise phonologically incomplete script, thereby helping the reader to decrease the amount of ambiguity s/he encounters when readings words, paragraphs, and texts. While semantic ambiguity is a common phenomenon in all languages, phonological ambiguity is remarkably frequent in Arabic. Still, the most studied form of ambiguity is semantic ambiguity (also known as lexical ambiguity) in which a single written word can represent many different meanings (e.g., *bat*) in contrast to an unambiguous word that is related to only one meaning (e.g., *clock*). By one estimate, these ambiguous words make up to 80% of the words in English and other languages (Klein & Murphy, 2001). Most studies of lexical ambiguity have used English words; they focused on written words that have just one way of being sounded out, but refer to more than one meaning (i.e. homonyms or homophonic homographs such as *left* and polysemes such as *mouth*). However, lexical ambiguity is not the only form of word-level ambiguity that occurs because of different possible relations among the semantic, phonological, or orthographic features of the word. Depending on the language and on the given word, the relationships between these features can be more or less straightforward, creating different kinds of ambiguity determined by the type of inconsistent relationships. For instance, the inconsistencies in homophonic homographs (e.g., *bat*) lie between orthography and meaning, while heterophonic homographs (e.g., *wind*) are inconsistent in terms of orthography on one side and phonology and meaning on the other.

In the current review, the key issue is the way phonologically ambiguous written words (e.g., *tear*) are stored, accessed, and read. Thus, to get a wider understanding of the resolution of ambiguity in reading, typical patterns of responses for semantically ambiguous words will be first reported (in lexical decision, naming, and semantic tasks), before examining in more details the way phonologically ambiguous words are processed. The results have been organized in term of whether the task is more or less semantically engaged, and of whether words are presented in isolation or within a biasing context (for a review, see Eddington & Tokowicz, 2015).

Overall, the most reliable semantic ambiguity effects in the literature can be summarized as follows:

- The ambiguity advantage is a robust and consistent finding in lexical decision.
- There is an ambiguity disadvantage in semantic tasks (e.g., categorization and relatedness judgment) that involve broad categories (e.g., 'Living Thing') and that involve response competition (i.e., the answer could be no).
- There is no ambiguity effect in semantic tasks based on narrow categories (e.g., 'Animal').
- Initially, context (unless extremely biasing) does not affect ambiguous word recognition, and all interpretations of the word are partially activated.
- Later on, context deactivates the inappropriate interpretation while the appropriate interpretation remains active in memory.

2.4.1 The Resolution of Lexical/Semantic Ambiguity

Lexical decision is one of the most frequently employed experimental paradigms to examine lexical processing and the resolution of lexical/semantic ambiguity (for a review of tasks used in ambiguity research, see Simpson, 1984; 1994). It is assumed to not necessarily require the complete semantic code to be activated for accurate responses, and might be used to examine early semantic access (Piercey and Joordens, 2000; Masson and Borowsky, 1995).

A considerable amount of research evidence supports the idea that single ambiguous words with multiple meanings yield faster responses than unambiguous words with one meaning in lexical decisions (e.g., Rubenstein et al., 1970, 1971; Jastrzembski, 1981; Kellas, Ferraro, & Simpson, 1988; Millis & Button, 1989; Hino & Lupker, 1996; Azuma & Van Orden, 1997; Borowsky & Masson, 1996; Pexman & Lupker, 1999). Even if some researchers have failed to observe this so-called "ambiguity advantage" in some tasks (e.g., Azuma & Van Orden, 1997; Rueckl, 1995), the majority of researchers have replicated the finding that ambiguous words with multiple meanings are responded to faster than unambiguous words with one meaning in lexical decision.

Moreover, when such an ambiguous word is put in a context during lexical decision, either by embedding it in a sentence, or by preceding it with a prime, the interpretation of its meaning becomes biased by the constraints of this particular context. Priming studies have shown that even when an ambiguous word is presented in context, both its meanings can be accessed. That is, a homonym presented in a sentence was reported to facilitate lexical decisions for targets that are related to both its meanings, even the one that is not implied by the sentence context (e.g., Onifer & Swinney, 1981; Seidenberg, Tanenhaus, Leiman, & Bienkowski, 1982; Swinney, 1979; Tanenhaus, Leiman, & Seidenberg, 1979). The appropriate meaning was found to be facilitated to a greater extent than that of the inappropriate one.

For instance, in one study, Onifer & Swinney (1981) used a cross-modal lexical priming task to determine how ambiguous words are accessed. In this task, participants made lexical decisions about written words (e.g., *weight-fish)* while listening to sentences that are biased toward either the dominant or the subordinate meaning of these words (e.g., *The postal clerk put the package on a postal scale to see if it had enough postage)*. Their results suggested that lexical decisions to words related to both the dominant (e.g., *weight*) and the subordinate (e.g., *fish*) meanings were facilitated when the word immediately followed the sentence. However, after a delay, only words related to the contextually relevant meaning (e.g., *weight*) were facilitated. These results were interpreted as a confirmation of a *context-independent (or exhaustive) model* of lexical access for ambiguous words in which all possible meanings of one word are retrieved at the same time in parallel, regardless of the context. The fact that the low-frequency meaning was accessed, even when the context biased the high-frequency meaning was taken as strong evidence that lexical access is an exhaustive and autonomous process in which the word is accessed automatically not considering the frequency of its meaning or the prior context. Context was claimed to be used subsequently for selecting the appropriate meaning and discarding the irrelevant one.

This interpretation was challenged by the data supporting the *ordered-access model* in which lexical access does not occur in parallel but is determined by the relative frequency of the meanings related to the ambiguous word (e.g., Duffy, Morris, & Rayner, 1988; Forster & Bednall, 1976; Hogaboam & Perfetti, 1975; Neill, Hilliard, & Cooper, 1988; Simpson, 1981). That is, whenever a reader encounters an ambiguous word, s/he retrieves its dominant meaning. If this meaning is inconsistent with the context, then it is discarded until a compatible match is found. Experimental evidence supporting this model can be found for instance in Simpson's investigations. In one experiment, Simpson (1981) demonstrated that only targets that were related to the dominant meaning of an ambiguous word were primed in lexical decision. In another set of experiments, Simpson and Burgess (1985) also used the time course of lexical decisions to targets associated with the dominant or the subordinate meaning of a homograph prime. Their results showed that access to ambiguous words is determined by the relative frequency of their two meanings. That is, the dominant meaning of the homograph was retrieved first, after a delay of 16 ms between prime and target. The subordinate meaning was activated more slowly when the lag between prime and target ranged from 100 to 300 ms. After being retrieved, activation of the subordinate meaning decreased after 300 ms. This decay of the subordinate meaning was interpreted with view of the limited-capacity attention system (Neely, 1977). In the absence of a biasing context, the reader must focus on only one meaning, and s/he usually selects the dominant alternative.

In a different model of ambiguity resolution, it is context and not meaning frequency that influences meaning activation. According to this *context-dependent model*, it is the contextually appropriate meaning that is mainly activated when the word is put in a sentence. In lexical decision, Simpson (1981) found, for instance, that when a sentence was strongly biased toward a meaning, only that meaning was facilitated in a crossmodal lexical priming task.

Overall, lexical decision studies (with and without context) supported all three models depending on the demands of the task and on the strength of the context. Therefore, resolving lexical ambiguity seems to be a complex phenomenon in which both meaning frequency and context interact to achieve lexical access (for a discussion, see Simpson, 1984; 1994).

In addition to the extensive literature using lexical decision, inconsistent results were found in naming tasks in which participants are required to pronounce written words aloud. While evidence for an ambiguity advantage has been found in many studies (e.g., Balota, Ferraro, & Conner, 1991; Fera, Joordens, Balota, Ferraro, & Besner, 1992; Hino & Lupker, 1993), no reliable ambiguity effects have been also reported (e.g., Borowsky and Masson, 1996).

Further, what is particularly germane to this work is the use of semantic paradigms that require the activation of semantic information to elicit appropriate responses. These experimental tasks have been deemed as a “purer” assessment of semantic processing than lexical decision. In fact, confounds such as orthography and its familiarity might contribute to speed and accuracy of lexical decision (Gernsbacher, 1984), whereas performance in semantic tasks depends directly on the activation of meaning. Therefore, performance on semantic tasks might provide more direct insights into the nature of semantic ambiguity effects, and the processes underlying them. These semantic tasks include a sensicality judgment task (SJT) whereby participants are asked if a particular sentence makes sense, a semantic categorization task (SCT) whereby participants are asked to decide whether a word belongs to a category or not, and a semantic relatedness/association judgment task (SRJT) whereby participants are asked to determine whether a pair of words are related or not.

In opposition to the ambiguity advantage reported in lexical decision, an ambiguity disadvantage is consistently reported in semantic tasks, even when using the same set of items that produced the advantage in lexical decisions (e.g., Hino et al., 2004; Piercey and Joordens, 2000). Gottlob, Goldinger, Stone, and Van Orden (1999) and Piercey and Joordens (2000) have both found an ambiguity disadvantage in their SJTs. In one experiment, Piercey and Joordens (2000) demonstrated an ambiguity advantage coupled with an ambiguity disadvantage for the same words across tasks. Participants were asked to make a lexical decision followed by a relatedness judgment to semantically ambiguous words (e.g., *bat)*. Lexical decisions were faster and more accurate for ambiguous words than unambiguous one, whereas relatedness judgments were slower and less accurate for the same words. The authors explained the findings within their efficient then inefficient model (for more details, see the efficient then inefficient account below): Lexical decisions can be made early in processing, when ambiguous words have an advantage, while relatedness judgments require a deeper semantic activation for a specific meaning of the ambiguous word to be obtained, and thus need more time to be achieved. Gottlob et al. (1999) also reported an ambiguity advantage for semantically ambiguous words in a naming task but an ambiguity disadvantage in a matched association-judgment task.

Alternatively, Hino, Lupker, & Pexman (2002) further investigated the ambiguity effects in semantic tasks by using semantic categorization instead. An ambiguity disadvantage was found in the semantic categorization task with the ‘Living Thing’ category using the same set of items that produced an ambiguity advantage in lexical decision. Similarly, Hino et al. (2006) conducted a series of semantic categorization experiments using the same set of Japanese words for which an overall ambiguity advantage was reported in lexical decisions. They investigated whether the ambiguity disadvantage is observed across categories by asking the participants to decide whether a word referred to a ‘Living Thing’, ‘Vegetable’, ‘Animal or Vegetable’, or ‘Human position, occupation, or group.’ Their experiments involved three word groups: ambiguous words with related meanings (i.e., polysemes), ambiguous words with unrelated meanings (i.e., homonyms), and unambiguous words. The results indicated that when broad categories were used (i.e., Living Thing, Human), there was a significant processing disadvantage for homonyms, and that responses in categorization tasks were significantly slower than in lexical decision. In contrast, when narrower ‘Vegetable’ and combined ‘Animal and Vegetable’ were used, no effect of ambiguity was observed at all. Responses were also of the same speed or even marginally faster than the lexical decision responses for the same words. Hino et al. (2006) suggested that this pattern of results was due to the differences in the decision-making strategies used in these tasks; in narrower category, participants are able to make a decision by checking a small number of features, whereas in broader category all the activated features would have to be checked before making a decision.

By also using semantic tasks, Klein and Murphy (2001) investigated the question of whether multiple meanings of ambiguous words are represented separately or not in a reader’s semantic system. They conducted an experiment using SJT with primes, and distinguished between polysemes that have related senses (e.g., *paper*) and homonyms that have unrelated meanings (e.g., *left*). The participants were asked to decide whether a noun phrase containing ambiguous words and modifiers made sense. The presented polysemes were preceded by primes that denoted the same sense (e.g., *shredded paper* preceded by *wrapping paper*) or a different sense (e.g., *shredded paper* preceded by *daily paper*). The results indicated that for ambiguous polysemes, the primes facilitated the phrase recognition only in the condition where they had the same sense as the target phrases (e.g., *shredded paper* was more quickly recognized if it was preceded by *wrapping paper* but not if it was preceded by *daily paper*). For phrases containing homonyms, the results showed that the priming effect sizes were similar to phrases containing polysemes. Based on these results, the authors argued that if polysemes were represented by only one abstract meaning, both same-sense and different-sense primes would have the same effect on the participant's responses, and priming size would be bigger for polysemes than for homonyms. They concluded that polysemes and homonyms are similarly represented separately in the readers' semantic system.

2.4.2 Theoretical Accounts of the Ambiguity Effects

Developing a model of semantic or lexical ambiguity is essential to understand how the orthographic and phonological aspects of words are mapped onto the semantic representation of their meanings. This review is not intended to be exhaustive; it will cover a few general theories of ambiguity resolution based on some of the previously reviewed empirical results. Overall, theories that model how readers process ambiguous words can be classified under two main frames of reference; the traditional/symbolic view and the connectionist view (for a discussion of the difference between the two views, see section 5.1.1. in this chapter). On the whole, the ambiguity effect might be assumed to be based on earlier perceptual/orthographic processing (e.g., Kawamoto et al., 1994), on later semantic processing (e.g., Piercey and Joordens, 2000), or even later on response selection processes (e.g., Pexman et al., 2004, Hino et al., 2006).

Traditionally, word recognition was conceptualized as the process of going from a printed letter string to its meaning that is stored in lexical memory. Within that localist framework, lexical memory or the "mental lexicon" was thought to be the representation of the words in the reader/listener's language system. The reported ambiguity advantage was initially explained within the classical lexical models framework. In such models, the ambiguity effect in naming and lexical decision is associated with a lexical selection process. For example, Jastrzembski et al. (1981) assumed that unambiguous words are represented by one lexical unit, while ambiguous words are represented by multiple lexical units. According to these authors, the ambiguity advantage can be explained by an increased probability of choosing an ambiguous word and hence a processing time advantage for ambiguous words. Similarly, Kellas et al. (1988) assumed that words are represented by individual nodes within an inhibitory lexical network; the different nodes associated with an ambiguous word inhibit all other competing entries without inhibiting each other, and this increased inhibition of competitors accelerates recognition times.

Alternatively, Balota, Ferraro, and Connor (1991) supposed that ambiguous words are represented by single lexical units that are linked to several semantic units and that there is feedback activation between the semantic and the lexical levels. According to their model, the ambiguity advantage is explained by the fact that ambiguous words are more densely represented at the semantic level, thus the feedback activation from semantic units to lexical unit results in faster lexical selection for ambiguous words.

In a different localist account of the ambiguity disadvantage in semantic tasks, Gottlob et al. (1999) suggested that all meanings of an ambiguous word are activated simultaneously, but that the dominant meaning suppresses the activation of the subordinate meaning through inhibitory links between all the semantic units representing the word. In such a scenario, Gottlob et al. (1999) predicted an ambiguity disadvantage in semantic tasks because of this competition between the different meanings of the ambiguous word that needs to be resolved before an accurate response can be made.

The previous discussed models assumed that words are organized together in the mental lexicon, and that the ambiguity effects in lexical decisions were mainly due to the lexical selection processes. Within a different framework, the ambiguity advantage can be explained without involving a localist lexical representations or a lexical selection process (Plaut, 1997; Plaut, McClelland, Seidenberg, & Patterson, 1996; Seindenberg and McClelland, 1989; Van Orden, Pennington, & Stone, 1990). Instead, in the models based on the *Parallel Distributed Processing* and in the case of ambiguous words, one single orthographic unit is associated with multiple semantic patterns corresponding to its different meanings, while for unambiguous words each orthographic unit corresponds to one single semantic unit. In simulation work, modelers can train the network to learn the mapping from orthography to semantics and test how quickly and accurately the model will ‘settle’ to a certain point according to different types of words. Because of this one-to-many relationships between orthographic codes and semantic codes, PDP models predict that semantic coding should be slower for ambiguous words than for unambiguous words. When the orthographic pattern is presented to the network, the network will try to simultaneously instantiate the word’s two meanings across the same set of semantic units. These competing semantic representations will interfere with each other, and will therefore delay the production of a stable pattern of activation. Based on this contradiction between the prediction of the PDP models and the observed ambiguity advantage in lexical decision, Joordens and Besner (1994) argued that the ambiguity effect can be considered as a major challenge to PDP models. Nonetheless, this contradiction can be resolved by several explanations, all within the PDP framework.

One example is the *orthographic account* developed by Kawamoto et al. (1994). This model supposes that performance in lexical decision is associated to the activation of orthographic units (Balota & Chumbley, 1984; Kawamoto, 1993; Seidenberg & McClelland, 1989) and not semantic units. To compensate for the inconsistent feedback from semantic units, ambiguous words develop stronger connection weights between orthographic units through error-correcting learning algorithm. On the other hand, unambiguous words rely more on the consistent feedback from semantics and develop weaker intra-orthographic mappings. As a result, the orthographic units settle more quickly for ambiguous words than for unambiguous words in connectionist simulation of a lexical decision task.

Alternatively, the PDP-based *feedback account* (Hino, Lupker, & Pexman, 1996) assumes that semantics impact lexical-decisions through feedback activation from the semantic level to the orthographic level. Within this model, the amount of feedback activation from the semantic level to the orthographic level is thought to be greater for ambiguous words than for unambiguous words, because ambiguous words would activate more than one meaning, and thus would receive more support from semantic feedback, which would produce the ambiguity advantage in lexical decision. On the other hand, semantic categorization tasks are assumed to engage semantic processing, and therefore, to be sensitive to the speed of semantic coding. It is then expected that ambiguous words would be at disadvantage in semantic categorization, because they would activate multiple meanings.

Still, later work by the same authors (Hino et al., 2006; Pexman et al., 2004) showed that attributing the ambiguity disadvantage in semantic tasks to response competition only, does not fully account for all the aspects of its effects. Pexman and her colleagues (2004) modified their initial explanation and alternatively proposed that this ambiguity disadvantage in semantic tasks is better accounted for by a decision-making stage rather than by a meaning-activation stage of the task. The decision system differences are thought to account for the differences of performance in categorization tasks between broad (e.g., living thing) versus narrow (e.g., vegetable) categories (Pexman et al., 2004), and for the different pattern of results between the yes versus the no trials of semantic categorization. Specifically, based on earlier suggestions and discussions (Borowsky and Masson, 1996; Kawamoto, 1993; Rueckle, 1995; Hino & Lupker, 1996, 1998), Hino and his colleagues suggest that the ambiguity disadvantage in semantic categorization tasks is not due to the semantic-coding process as they had previously claimed , but instead to the decision-making conflict between two possible answers yes and no, and when the categories used (e.g., Living Thing) were broader than categories that contained a smaller set of core semantic features (e.g., Animal).

In another PDP model termed the *efficient then inefficient processing* model, Piercey and Joorden, (2000) argue that by activating multiple meanings, ambiguous words quickly create a ‘blend state’(i.e., a pattern of activation that does not represent either meaning of the word) (Joordens & Besner, 1994). This model is best understood in the context of the ambiguity advantage in lexical decision, in opposition to the ambiguity disadvantage in reading performance. It claims that different tasks require different levels of semantic activation: lexical decisions can be made before semantic coding is completed, and they only require the activation of an incomplete “blend state” based on whether a written word has any meaning at all, while word reading requires a more complete fully settled semantic activation pattern that a blend state may not be unable to provide.

Piercey and Joordens (2000) describe two consecutive stages of ambiguity resolution. First, a fast and efficient initial stage where the semantic activation of an ambiguous word moves toward a pattern that is a blend of its different meanings. In this blend state, all meanings of an ambiguous word are partially activated. Then, if appropriate, a slower and less efficient second stage where the semantic activation pattern moves out of the blend pattern and toward one of the specific meaning patterns.

2.4.3 The resolution of Phonological Ambiguity

In addition to the lexical/semantic ambiguity in which both orthography and phonology activate more than one meaning (e.g., *bat*), phonological ambiguity is another form of ambiguity in which orthography can still activate two meanings, but phonology does not (e.g., *tear*). Whenever phonological ambiguity is resolved in such a case, the meaning of the word is directly disambiguated. Both types of homographs are similar in that one orthographic pattern is associated with multiple meanings, but they are different as to the relationship between orthography and phonology.

Of particular relevance for the present research, are the studies of Folk and Morris (1995), Gottlob et al. (1999), and Carpenter and Daneman (1981, 1983) that investigate the resolution of phonological ambiguity by having participants respond to heterophonic homographs. Their results generally converge towards the suggestion that the latency for processing heterophonic homographs is significantly longer than that for non-homographs especially when they carry a subordinate meaning, possibly reflecting a time-consuming disambiguation processes in which the reader suppresses all the irrelevant automatic meanings related to the word.

In more detail, it seems like both the dominant and the subordinate representations of heterophonic homographs are initially accessed in the absence of a biasing context. Folk and Morris' investigations (1995) used eye-movement and behavioral studies on words having multiple sources of ambiguity (i.e. semantic, phonological, and orthographic) to better understand how phonological, orthographic, and semantic codes interact in word recognition and text integration. For the purposes of the present research, the results of heterophonic homographs are of particular interest.

In Folk and Morris' Experiment 1, eye-movements were monitored in sentences containing a target heterophone (e.g., *sewer*). In each sentence, disambiguating information biasing the subordinate meaning of the target word followed the word (e.g., *since the old sewer was awful, the tailor's shop got a bad reputation*). The following pattern of results has emerged: participants spent initially more time processing heterophonic homographs than homophonic homographs or controls. They also spent more time in the following disambiguating region (e.g., *the tailor*) for both homophonic and heterophonic homographs. Once they reached the disambiguating region, they reread back the target words only when reading heterophonic homographs. The authors attributed this difference between homophonic and heterophonic homographs to phonological competition. That is, in a neutral context the dominant meaning of a homophone (e.g., *calf*) is activated with little or no competition from the subordinate meaning as the participants processed these words like any other unambiguous words. Conversely, all representations of heterophonic homographs seem to be initially accessed regardless of dominance as showed by the increase in initial fixation times to these words. This observed initial difficulty in processing heterophonic homographs reflect the time-consuming competition between the two pronunciations of the word. Later when the participants reached the disambiguating region, they did not need to regress back to the homophonic homographs (e.g., *calf*) because the initial pronunciation was still active and could be used to recover the alternative version of the word. In contrast, when reading the disambiguating information, participants made regressions back to the heterophonic homographs (e.g., *sewer*) to access the alternative phonological code and the meaning associated with it because the original code activated was not useful anymore to recover the correct meaning.

Folk and Morris' second experiment was similar to Experiment 1, with the exception that the disambiguating information which biased the subordinate meaning preceded the ambiguous words instead of following them. Results indicated that participants had more difficulty processing homophones (e.g., *calf*) than in Experiment 1, likely because the preceding context boosted activation of the subordinate meaning, resulting in competition between the dominant and subordinate meaning. Similarly, heterophones (e.g., *tears*) took more time to be processed, however the size of the effect in Experiment 2 (40 ms) was significantly lower than that of Experiment 1 (80 ms), suggesting that context mediated the competition between the two versions of the word but did not resolve it. In addition, participants still had difficulty maintaining the correct meaning of the heterophonic homographs in mind, and thus they had to reread these words more often than controls andhomophones.

In Experiment 3, Folk and Morris investigated phonological processing more directly by using a naming task in which the participants named the target words of Experiment 2 after reading the first part of the sentence silently. Again, results showed that participants had initial difficulty naming the heterophonic homographs both by making more errors and taking more time in sounding them out, even when the context biased the meaning. Folk and Morris concluded that when reading heterophonic homographs, early phonological competition between the different meanings of the word makes selecting even the dominant meaning difficult.

Folk and Morris' Experiment 4 was designed to clarify whether readers can overcome this initial difficulty and understand an ambiguous sentence by making the appropriate interpretation of the target ambiguous word. Participants were therefore asked to read the sentences of Experiment 2 aloud and to answer comprehension questions. Results showed that participants did understand the contextually appropriate meaning of all ambiguous words by the time they finished reading the sentence. Again, initial processing difficulty (increased number of errors) was found for heterophones (e.g., *tear*). Still, when participants made pronunciation errors, they corrected their initial mistakes immediately on 90% of the trials.

Following this general pattern of results, Folk and Morris (1995) suggested that reading a single heterophonic homograph (e.g., *tears*) activates almost simultaneously two or more phonological codes each related to one meaning, even when the word has a predominantly dominant meaning, or when it is presented in a biasing context. This results in competition from which readers must select the context-appropriate meaning. When readers are provided with preceding or later context, consistent with the subordinate interpretation, they have more difficulties in processing heterophones than any other ambiguous or control word. Besides, readers who select the incorrect interpretation have to reread the heterophone to recover the contextually appropriate subordinate.

Complementary to the previous studies, Gottlob et al. (1999) examined reading performance to heterophonic homographs, in addition to homonyms and control words. The figure below schematizes the networks used for different types of words (i.e., homophones, heterophonic homographs, control words). It illustrates how different configurations represent processing for each type of words, and can be used to give a clearer insight on the experiments' results.

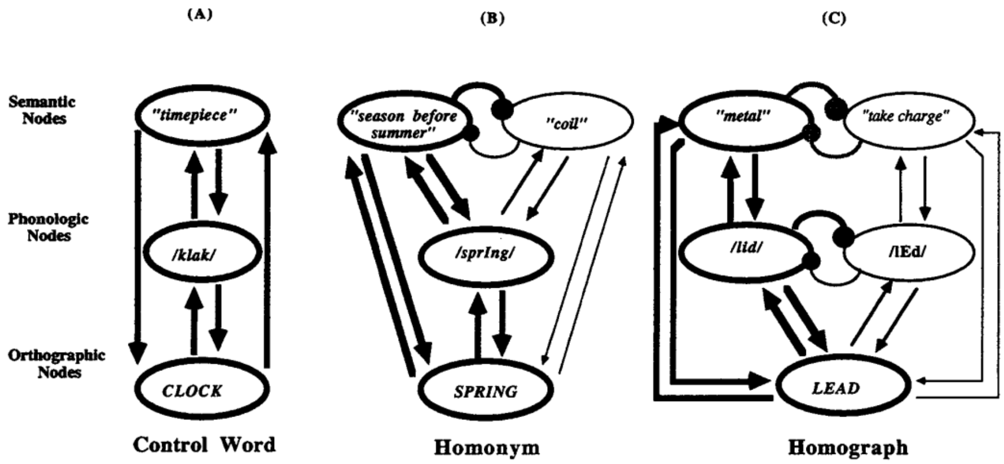

Figure 2.2: Schematic networks for three types of stimulus words (Gottlob et al., 1999).

Similarly to Folk and Morris (1995) and Kawamoto and Zemblidge (1992), Gottlob et al. (1999) observed a homograph disadvantage in naming. By the authors' account, the homography disadvantage can be explained by figure 1: Heterophonic homographs have two separate phonologic and semantic nodes that provide discordant feedback as to how pronounce the word. This competition between the two potential pronunciations (and meanings) requires additional time to be resolved. As typically one node is stronger than the other (dominant meaning), this leads to one pronunciation usually winning. Furthermore, in a semantically more engaged task (word-association judgment) with the target heterophonic homograph preceding its associate (e.g., *wind-breeze*), heterophonic homographs had different results depending on the dominance of their associates: if the associates had dominant meaning, performance was similar to controls, whereas performance with subordinate meaning was extremely slow and inaccurate. The authors predicted these results using the model of figure 1: each meaning of a heterophonic homograph has only one pronunciation, and therefore if the reader activates the correct pronunciation, associations should be fairly quick and accurate. However, if the reader activates the alternative pronunciation, s/he should restart the whole perceptual process, significantly delaying performance, or making it more error-prone. With the addition of semantically biasing primes before the target words (e.g., *breeze-wind*) in a third experiment, heterophonic homographs were again initially interpreted as their dominant form even when primed with their subordinate meaning. That is, participants detected the dominant relationship faster and more correctly than the subordinate one. Moreover, while dominant pairs were detected at nearly the same accuracy and speed of control words, subordinate pairs were slower to be detected and more error-prone. These results replicate those of Folk and Morris (1995) who observed that the participants pronounced the more dominant meaning even with astronger biasing context towards the subordinate meaning (i.e., sentence frame) than the primes used by Gottlob et al. (1999).

Overall, it seems like the disambiguating semantic constraints of context used by both Folk and Morris (1995) and Gottlob et al. (1999) were too weak to override the dominance effect of earlier orthographic-phonologic associations. The stronger O-P connection (dominant meaning) seem to guide reading comprehension, even when the context biases a subordinate meaning. Still, the context influenced the relative availability of the phonological codes in some way, making processing easier for heterophonic homographs as observed by the fact that the magnitude of the effect on the heterophones in neutral context is twice that observed in the presence of prior biasing context (Folk and Morris, 1995).

Further, Carpenter and Daneman (1981) studied how readers initially interpret heterophonic homographs within a context and how they detect and revise their incorrect interpretations, by using eye-movement-tracking in reading passages aloud. They used "garden path" passages that initially prime one meaning of a heterophonic homograph and then assume its other meaning. An illustration of such a passage using the homograph tears (droplets or rips) would be “Cinderella was sad because she couldn't go to the dance that night. There were big tears in her brown dress”. The results indicated that balanced heterophones that have two similar availabilities (e.g., bass, wound, bow, winds, lead, close, and read) were generally but not always interpreted as the more strongly primed homograph, whereas “less ambiguous” heterophones that have one dominant meaning (e.g., tears, buffet, sewer, shower, row, and minute) were almost never interpreted as the homograph with the lower availability (e.g., row as fight), even when they were primed by the context. Moreover, when a more biasing context was provided, the stronger context did increase the rate of subordinate interpretations that were produced, indicating that the pronunciation of heterophonic homographs was influenced by both the prior biasing context and by the relative frequency of the word.

In a subsequent study, Daneman and Carpenter (1983) compared read-aloud and silent-reading comprehension of passages containing semantically ambiguous homophonic homographs (i.e., homonyms such as bat) to passages containing phonologically ambiguous heterophonic homographs (e.g., sewer). Participants were asked to read passages in which the appropriate meaning of a heterophonic homograph was switched (e.g., from the drain meaning of sewer to the tailor meaning of sewer) and then to answer comprehension questions that required them to retrieve the initial interpretation of the ambiguous word (e.g., the drain meaning of sewer). The results indicated that passages containing a phonologically ambiguous word (i.e., heterophonic homographs) were less accurately understood than passages containing a word that was only semantically ambiguous (i.e., homophonic homograph/homonym). The authors used these results as evidence that the two phonological representations of the word were kept active in working memory, thus creating interference and making comprehension more error prone.

In simulation work, by using a PDP model, Seidenberg and McClelland (1989) successfully reproduced this homography disadvantage. When their model was trained to read a non-homograph, a strong association was established between orthographic and phonological representations because a single orthographic pattern of activation was always mapped onto a single phonological pattern of activation. On the other hand, when the model was trained to read a heterophonic homograph, the associations established between the single orthographic pattern and the two phonological representations were weaker because the weights for one of the orthographic-phonological associations was altered during the process of learning the other association. Therefore, it took more time for the model to settle on a response for the heterophonichomograph because of the weaker relationships between orthography and phonology. Likewise, Van Orden et al. (1990) described heterophonic homographs as having two attractors in a phonological space. Initially, heterophonic homographs are coded between attractors but closer to the dominant version. The processes that drive perception to a final attractor is influenced by meaning dominance, pronunciation regularity and biasing context among others.

2.5 Models of Visual Word Recognition and Reading: From General to Orthography-Specific Models

Key results from the previously discussed studies can support theoretical models of skilled reading in Arabic. After all, the ultimate objective of this thesis is to extend our knowledge of the mental mechanisms involved in Arabic reading. Therefore, looking at general models of reading along with more Semitic-specific models is essential to enhance our understanding of the cognitive processes that occur when the reader performs the experimental tasks in the following experiments.

Models of reading have been traditionally developed based on results in Latin script, and more specifically in English orthography. One of the reasons behind this limitation is the assumption that reading like other cognitive processes is universal, and that studying reading in one language is sufficient to draw conclusions about the cognitive processes involved in reading across writing systems and languages. However, the universality of such models has been recently questioned (Frost, 2006; Share, 2008), thereby eliciting new reading models in less studied languages such as Arabic.

In the following paragraphs, general models of reading will be introduced to provide a clear framework under which all models of reading Arabic will be understood. Traditional/symbolic and connectionist views of how Arabic (and Hebrew) readers recognize words and how the language-specific features of Arabic (and Hebrew) affect its processing will be discussed. One particular influential proposal on the way differences in orthography lead to processing differences in reading, *the orthographic depth hypothesis*, will be emphasized given its marked pertinence for analyzing the data of this study.

2.5.1 General Models of Visual Word Recognition and Reading

Numerous models of word-recognition have been proposed in the literature of the past 40 years to better understand reading processing. These include the Interactive-Activation (McClelland & Rumelhart, 1981), Activation-Verification (Paap, Newsome, McDonald, & Schvaneveldt, 1982), Multiple-Levels (Norris, 1994), Multiple Read-Out (Grainger & Jacobs, 1996), Multiple-Trace Memory (Ans, Carbonnel, & Valdois, 1998), and Bayesian Reader (Norris, 2006) models. Most recently, computational models have been widely used as tools to develop and test cognitive theories of reading. These are computer programs that mimic reading in a way that the modeler believes to be the way in which human read, by using the information-processing procedures specified in a cognitive theory of reading.

The focus of this work will be to describe the most representative computational models of reading. Therefore, this review will not look all possible models of word recognition and reading, but will rather discuss the two most prominent ones, the symbolic-dual-route models (e.g., Dual Route Cascaded, Coltheart et al., 1993; 2001), and the connectionist-distributed processing models (e.g., triangle connectionist approach, Harm and Seidenberg, 1999, 2004; Plaut et al.,1996; Seidenberg and McClelland, 1989). Both approaches have been extensively used in the literature as the basis for sometimes conflicting interpretations of psycholinguistic data

2.5.1.1 Computational Models of Reading: Symbolic Versus Connectionist Models.

Historically, two forms of models have been used to better represent how word recognition and reading operate. Symbolic models are computationally encoded versions of “functional architecture of the cognitive system” or box-like cognitive theories involving inputs, processes, and outputs, while connectionist models are neurally inspired models that attempt to model information processing the way it takes place in the brain. They assume that information occurs through interactions of large numbers of simple processing elements called units, each sending excitatory and inhibitory signals to other units." (Hinton, McClelland, & Rumelhart, 1986).

Those two classes of models differ in several ways. Most importantly the nature of representation varies between both models. While it is considered as local in symbolic models, connectionist models define it as distributed. According to symbolic models, words are represented locally in the reading system (i.e., the lexicon), where a word corresponds to a single unit (i.e., lexical entry). In opposition, representations are mostly distributed in connectionist models. That is, one word is represented by the activation of many simple sub-symbolic units in the system (e.g., representations of orthography, phonology, semantics, and context), and any unit in the system plays a role in representing different words. Moreover, the nature of processing varies between the two models. In connectionist models, all processing goes on in parallel. For example, when a non-word is presented to the model, all the letters are processed by the model simultaneously. In contrast, components of symbolic models operate at least partly serially. For example, the non-lexical procedure in the DRC model translates letters to sounds one letter after another, from left to right. Finally, learning is a major difference in the way the two classes of models are theorized. In connectionist models, learning is fundamental as knowledge develops over time through learning by adjusting the strengths of the connections in the model so that the model’s response to each word in its training set becomes progressively more accurate. In contrast, while the knowledge of reading skills is assumed to be gradually acquired by children, the dual-route model is only a static description of the mature information-processing system that children acquire as a result of their initial learning.

2.5.1.2 *A Symbolic Non-Connectionist Model of Reading: the Dual-Route Cascaded (DRC) Model (Coltheart, Curtis, Atkins & Haller, 1993)*

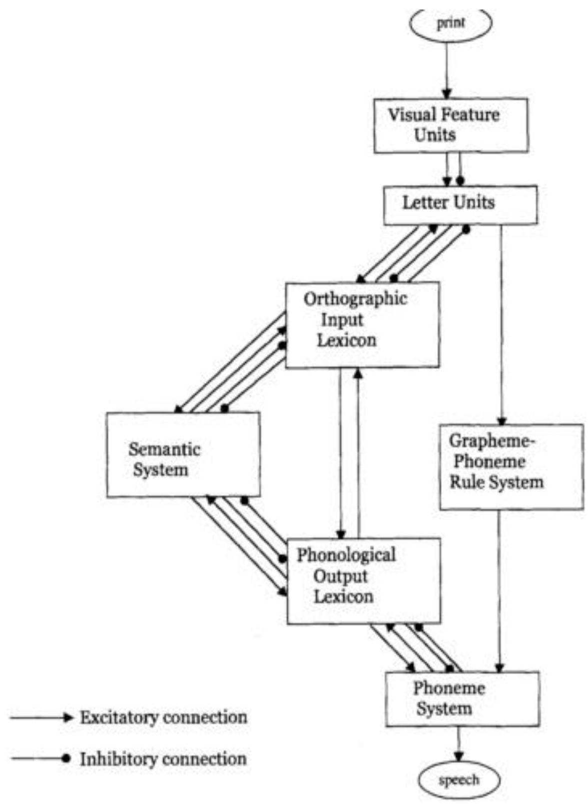

Figure 2.3: The dual-route cascaded model of visual word recognition and reading aloud (Coltheart et al., 2001).

The contemporary DRC simulation model (Coltheart et al., 2001) derives from predating cognitive "box and arrows" models such as the Forster and Chambers (1973) and the Marshall and Newcombe (1973) models. Like earlier symbolic models, it views the reading system as modular (i.e., domain-specific) in structure, and the box-and-arrow notation as optimal for describing its hypothesized architectures. The dual-route idea was first introduced by Forster and Chambers in 1973. According to the authors, naming written words involves giving a phonological code to a written string either indirectly by letter-sound correspondence rules, or directly by searching the long-term memory for the way a (familiar) word is pronounced. Whichever process is completed first controls the output generated.

This idea that skilled readers have at their disposal two information processing routes to reading is fundamental to all dual-route models of reading (e.g., Forster & Chambers, 1973; Kay & Bishop, 1987; Marshall & Newcombe, 1973; Morton & Patterson, 1980; Paap & Noel, 1991). Among others, the DRC assumes that skilled readers have at their disposal two different procedures for converting print to speech. The first one is the lexical route for irregular words: This is an internal dictionary (mental lexicon) lookup procedure. Readers access the word’s lexical entry directly from its printed form, and retrieve from that entry the word's pronunciation. The lexical route will succeed when the input is a word but will deliver no output when it is a non-word. The second route is the grapheme-to-phoneme route (GTP; non-lexical) for regular/new/non words; this is a letter-to-sound rule procedure that specifies the relationships between letters and sounds. Readers can read unknown pronounceable letter strings such as non-words that do not possess lexical entries. This nonlexical route allows the correct reading aloud of pronounceable non-words and of words that obey the spelling-sound rules but it delivers incorrect translations of the "exception" or "irregular" words (e.g., pint).

The distinction between two independent processes in reading was developed based on findings from experimental psychology and from neuropsychology indicating for example that brain damage can lead previously skilled readers to have selective difficulty in reading either non-word in phonological dyslexia (Funnell, 1983), or irregular words in surface dyslexia (Patterson, Marshall, & Coltheart, 1985).

In addition to the dual-route for reading, a second important assumption made by DRC is that information processing is cascaded in a way that information passes onto later stages after any amount of activation at any stage, as opposed to threshold processing that passes activation to a next stage only when the activation at the initial stage reaches a threshold. The cascaded component of the DRC is based on McClelland & Rumelhart's (1981) Interactive Activation and Competition (IAC) model.

The DRC uses two lexicons, one orthographic and one phonological, and it has no semantics defined. Parameters which govern excitation and inhibition within the model are pre-defined. Its internal structure is hard-wired to reflect the box-model architecture on which its theory is based (see Coltheart et al., 1993; 2001).

2.5.1.3 Connectionist Models of reading: the Parallel Distributed Processing (PDP) 'Triangle' Models

Similarly to dual-route models, word recognition in connectionist models (Harm & Seidenberg, 1999, 2004; Plaut et al., 1996; Seidenberg & McClelland, 1989) involves processing phonological and lexical material, but instead of running through separate routes to a mental lexicon, the information is supposed to be gathered in a melting pot, where it creates meaning. In contrast to dual route models, connectionist models aim to provide a model of reading, based on lexical knowledge, rather than rules. For them to become more efficient, readers are supposed to gradually recognize grapheme to phoneme correspondences as characteristic spelling patterns encountered several times, rather than as a set of rules. As such, connectionist models rely on three basic principles: The representation of information is distributed (not local), memory and knowledge for specific things are stored in the connections between units (not explicitly), and learning can occur with gradual changes in connection strength by experience.

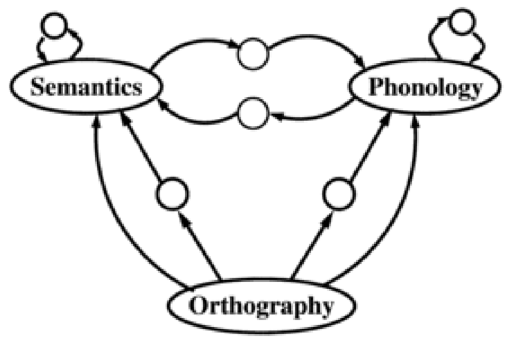

Figure 2.4 The triangle models used in connectionist models of reading.

Connectionist models develop through a learning algorithm, and are typically based on a network with three layers (input units, hidden units, output units) with weights between units having initially small random values. Each word is represented as a unique pattern of activation across a set of orthographic, phonological and semantic units. These units are interconnected and are weighted in a way that reflects the nature of the relationships between them. With relation to such model "knowledge of words is embedded in a set of weights on connections between processing units encoding orthographic, phonological, and semantic properties of words, and the correlations between these properties" (Seidenberg & McClelland, 1989). A written word activates orthographic units that later spreads to semantic and phonological units through those weighted connections. The speed and accuracy of semantic and phonological activation depends on relationship among orthographic, phonological, and semantic units. A large training set of stimulus-response pairs is submitted to the model, so that the learning algorithm progressively adjusts the network's connection weights in a way that for each stimulus (representation across the input units) the response (representation across the output units that is evoked by that input) gradually resembles the correct response. Unlike the previous DRC model, the architecture of a connectionist model is developed by a learning algorithm, rather than specified by its creators. The majority of connectionist models use a 'triangle' model, referring to the three components of the model, the orthographic input, phonological output, and a semantic component. The addition of the semantic component underlies the assumption that word recognition relies on a combination of phonological and semantic information. The three components and the hidden units are interconnected, and are theoretically capable of being modified by any unit they are directly connected to.

2.5.2 Reading models in Arabic and Semitic Orthographies

2.5.2.1 The Organization of the Mental lexicon in Arabic and Semitic Orthographies

The findings from masked priming (Frost et al., 1997) and letter-transposition priming in Arabic (Perea, Abu Mallouh, & Carreiras, 2010) and Hebrew (Velan and Frost, 2009, 2011) suggest that the Semitic lexical space is different from the Indo-European one. That is, while the Indo-European lexicon is organized orthographically with words having specified locations according to their letters (and some flexible coding of their position), the Semitic lexicon is organized morphologically according to the words' roots (for more details on the morphology of Arabic, see previous paragraphs), with words having specified locations according to their root, but not to their orthography. For example, طريق */tari:q/ road* and بريق */bari:q/ glitter*, are derived from the same word-pattern but from two different roots **(***trq and brq***,** respectively). These two derivations would have been considered "orthographic neighbors" in English lexical space, since they share all of their letters but one, but in Arabic lexical space they would be located far apart because they are derived from different roots.

According to Frost and colleagues (Frost et al., 1997, 2005; Deutsch et al,. 2003; Deutsch et al,. 2000, 2005; Velan et al. 2005; Velan and Frost, 2007, 2011), word recognition in Semitic languages relies on a preliminary root-extraction phase that generates a morphologically based code (Velan and Frost, 2011). In their account, both lexical units (words) and sub-lexical units (morphemes) are represented in the mental lexicon. These two levels are interconnected so that the root can be accessed either at the lexical level from words containing that root) or by directly following a process of morphologically decomposing the orthographic structure. Processing of words consists therefore of both and sometimes simultaneous lexical retrieval (in which lexical units are located at the word level) and a morphological decomposition (in which morphemic units are extracted and located at the sub-lexical level).

In a similar way, by using cross-modal and masked priming, Boudelaa (2014) proposed that the extraction of roots and patterns in reading is sub-served by an obligatory parsing mechanism that he calls the *obligatory morphological decomposition* (OMD) process whereby the word's roots and patterns are accessed as lexical entries. A lexical entry will include the morphosyntactic, phonological, semantic and functional information related to the morphemes of a given word. Any word will undergo a decomposition of its constituent morphemes, so that it better recognized. Indeed, as explained elsewhere in this chapter, most of the Arabic words sharing the same root have overlaps in meaning. The root ktb for instance has 31 derived forms in Modern Standard Arabic that evolve around the general meaning of 'writing' (all but one *Kati:bah* squandron) (Boudelaa and Marslen-Wilson, 2010). Written words and their meanings are therefore generally not completely arbitrary; their mapping is more or less consistent. This promotes the development of the OMD process that extracts the root, thereby clarifying the general meaning of the word.

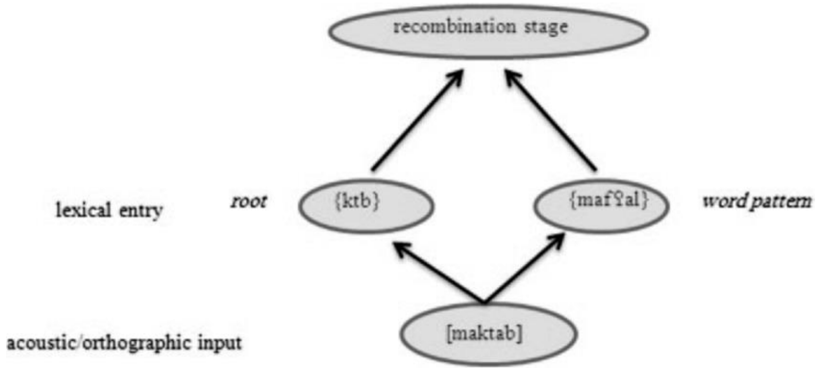

Figure 2.5: The Obligatory Decomposition view of Arabic spoken and written word recognition (Boudelaa, 2014).

2.5.2.2 The Interface Lexical System in Semitic Orthographies

Frost (e.g., Bentin and Frost, 1987; Frost, 1992, 1998, 2012) proposes that lexical decision in Hebrew is based on an "interface lexical system" that is an abstract linguistic representation (i.e., the consonantal structure of the word) described as underspecified (vs. detailed) shared by the several phonologic (and thereby semantic) alternatives of a written string (i.e., heterophonic homographs). That is, lexical decision (vs. naming) involves the recognition of a phonologically ambiguous consonantal string as accurate, but it does not require any additional detailed phonological analysis of this structure. The findings that lexical decisions are faster for undiacritized heterophonic homographs than any of their diacritized alternatives (Bentin and Frost, 1987), and that lexical decision for heterophones is as quick as that for homophones (Bentin et al., 1984) were taken as evidence supporting the idea that lexical decision in undiacritized Hebrew does not necessarily involve (pre- or post-lexical) phonology, but that it is rather based on an abstract and phonologically impoverished morphophonological entity (i.e., the word without vowels). During lexical access, the reader recognizes the abstract representation as a valid morphological structure without processing it further for more phonological clarity.

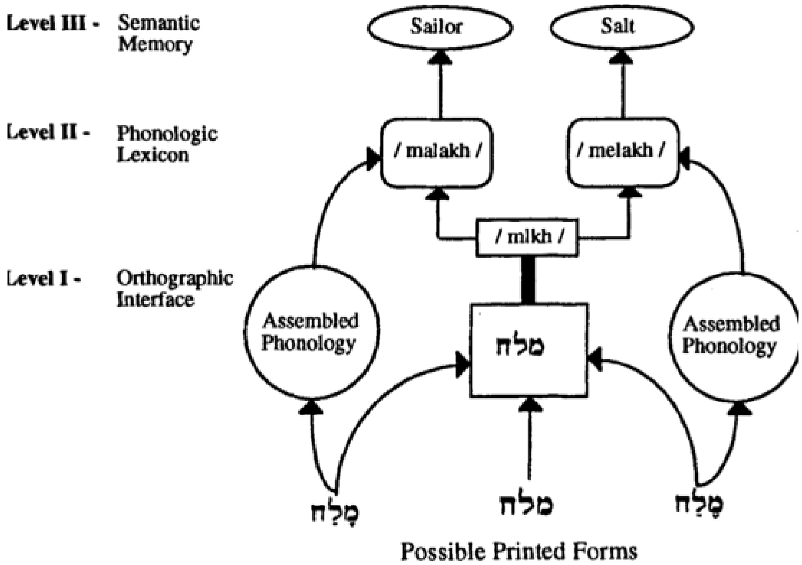

Figure 2.6: A model of the lexical structure of the Hebrew reader and the possible processing of pointed and unpointed printed words (Frost & Bentin, 1992).

2.5.2.3 Lexical Access to Ambiguous Words in Semitic Orthographies

Previous research (e.g., Bentin, 1989) supports the idea that when the script is presented without diacritics, the reader is forced to retrieve the missing vowels directly from the lexicon. This process is easily carried out when the word is unambiguous, but more difficulty is expected when the word is a heterophonic homograph that has several pronunciations from which the reader has to choose. Based on research findings including those with the role of vowels in lexical decisions (Bentin et al. 1984; Frost 1991; Frost and Bentin 1992; Frost and Kampf 1993), Frost and Bentin (1992) proposed an original model of lexical access to ambiguous words in Hebrew, and by extension in Semitic languages including Arabic.

In undiacritized script, a phonologically ambiguous word i.e., (heterophonic homograph) automatically activates different lexical entries, but at different times, with higher frequency words (i.e., dominant meaning) being accessed before lower frequency words (i.e., subordinate meaning). This is in line with findings in English that support the ordered-access model (e.g., Simpson and

Burgess, 1985) in retrieving ambiguous words. Evidence supporting this claim is found in Bentin and Frost’s work (1992) using delayed priming with heterophonic homographs. Results indicated that only the dominant meaning was active after a short delay, while the both meaning remained active after a longer delay (for more details, see paragraph 3.1.1). Compared to English (Simpson and Burgess, 1985), both meanings (especially the subordinate one) of the phonologically ambiguous word remained active for longer periods. One possible reason behind this difference is the fact that readers of Semitic orthographies develop strategies to disambiguate the common heterephonic homographs by keeping both interpretations of the letter string in memory until they reach a following disambiguating context. In contrast, a phonologically unambiguous/semantically ambiguous word (i.e., homophonic homograph) has only one lexical entry that activates two or more semantic nodes in parallel. Semantic nodes are more strongly activated when the given lexical entry has only one semantic entry as opposed to different semantic nodes for one lexical entry.

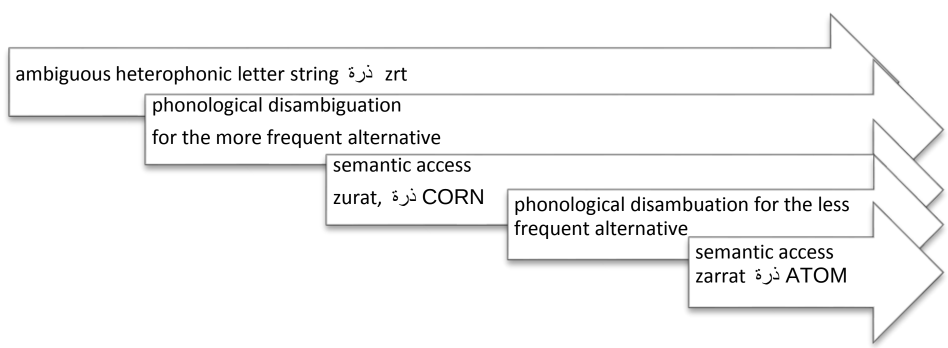

Figure 2.7: An ordered-access model to ambiguous words in Arabic (inspired from Frost et al., 1992).

These hypothesized models can account for the greater priming effect found for ambiguous words as overall, priming effects were more robust when the primes were phonologically ambiguous than not. According to this model, semantic nodes are more strongly activated when the given lexical entry has only one semantic entry as opposed to different semantic nodes for one lexical entry. The models also explain the lack of frequency effect found for homophonic homographs and for the vocalized heterophonic homograph: because the activation of a lexical entry in this case automatically activates all its corresponding meanings, the relative frequency of each meaning does not affect lexical access at this point.

2.5.2.4 Reading Strategies for Processing Diacritics in Semitic Orthographies

One particularity of Semitic writing systems including Arabic is that their readers can in reality read two orthographies, one that relies on partial phonological information (i.e., the undicritized script) and the other that provides all phonological information in written (i.e., the diacritized script). The experiments investigating processing diacritics have been reported in prior paragraphs. Their results indicated that the diacritics' role is not consistent across tasks and words; diacritics may facilitate, hamper, or they may not play a role in reading depending on the requirement of the task and the type of stimuli presented to the reader (e.g., Bentin and Frost, 1987, Koriat, 1984). Likely causes for discrepant results might reflect the different strategies used by the readers to process Arabic and Semitic orthographies depending on the provided amounts of phonological data. Indeed, investigations of the role of diacritics in reading have been typically carried out as part of a general effort to determine the role of phonology in reading. Therefore, studying diacritics processing in Semitic orthographies is particularly relevant in view of the additional data it can provide on the reading strategies applied by the reader to process an orthography that species either partial or full phonological information.

Some evidence has been found that readers of Hebrew and possibly other Semitic orthographies cannot ignore diacritics even if they are instructed to do so, and even if they do not need those additional diacritics to perform the task accurately (Navon and Shimron, 1981; Bentin, 1989). For instance, LDs for diacritized words were slowed down when the word without diacritics was legal while diacritics were incorrect, even when the participants were asked to ignore vowels when making their decisions (Navon and Shimron, 1981). Also, diacritized words were sensitive to phonemic repetition (seeing a different word that is pronounced similarly) but not to orthographic repetition (seeing a word but with different vowel diacritics) while undiacritized words were sensitive to both repetitions after a short lag, and to none after a longer lag (Bentin, 1989).

Consistent with the orthographic depth hypothesis (see paragraph below), Bentin (1989) suggested that the observed patterns reflects the fact that adding diacritics to a word directs the readers' attention to such marks, thereby inducing a phonological assembled procedure even if it not needed, while undiacritized words encourage the readers to use an orthographic addressed procedure. It seems like post-lexical (i.e., addressed) phonology is mainly at work in naming Hebrew words, especially when the script is undiacritized. That is, evidence has been found from Hebrew (e.g., Frost et al., 1987) that the lexical status of the word (e.g., word/non-word, high-/low-frequency) had the same effect on both LDs and naming tasks, thereby suggesting that the pronunciation of the word was retrieved post-lexically directly from lexical memory, without going through an assembled routine. What is more, the lexical status of the word had the biggest effect in the deep undiacritized Hebrew as compared to the shallower English and Serbo-Croatian orthographies, suggesting that the reader relies on the lexicon to name undiacritized script. This may stem in part from the fact that readers of Semitic orthographies are usually exposed to a deep undiacritized print, leading them to develop direct-route reading strategies that generate the missing vowel information in print. In addition to the crucial importance of post-lexical phonology while reading Semitic orthographies, a certain amount of pre-lexical (i.e., assembled) phonology seems to be also at work while reading both ambiguous and unambiguous, diacritized and undiacritized words. In more details, delaying the addition of vowel diacritics affected naming but not lexical decision (Frost & Bentin, 1992). Even if this effect was especially important for ambiguous heterophonic homographs, it was still present for unambiguous words. These results suggest that readers use both a pre-lexical strategy (effect bigger on naming than LD) and a post-lexical strategy (effect bigger in naming for ambiguous than unambiguous) to generate phonological information from print.

2.5.2.5 The Orthographic Depth Hypothesis

For Arabic and Semitic languages in general, the baseline exploration of the differences in the reading process in different languages has been the *orthographic depth hypothesis (*ODH) (Katz & Feldman, 1981; Feldman & Turvey 1983; Frost, Katz & Bentin, 1987; Katz Frost 1992). This paragraph focuses on this hypothesis by describing the way specific characteristics of different orthographic systems shape the mental processes involved in skilled reading, and by discussing how those differences apply to Arabic and Semitic orthographies (For a discussion of orthographic depth and transparency, see section 2.2. in this chapter).

All theories of visual word recognition agree that reading involves the processing of orthographic and phonological information. Since this information is conveyed differently in each language, whether cross-language differences influence the way reading is processed is therefore of central importance. Are all written languages processed the same way, or are there orthography-specific aspects that need to be taken into consideration? The orthographic depth hypothesis (ODH) suggests that differences in orthographic depth leads to differences in processing printed words, especially in naming and in lexical decision.

In a shallow orthography, readers are encouraged to assemble phonology by applying a simple *grapheme-to-phoneme conversion* (GPC) directly from printed letters sublexically. Because the mapping between letters and sounds is relatively direct and unambiguous, phonology is more easily available to the reader sublexically. In contrast, deep orthographies encourage a reader to process printed words' morphology via their visual-orthographic structure. Because of the less systematic mapping between spelling and sound, readers cannot generate phonology easily sublexically; instead, they rely to a greater extent on the easier direct and fast visual access to the lexicon to retrieve its phonology.

Overall, ODH's argument is that a fast visual/lexical route is available in all orthographies. If readers of shallow orthographies still prefer a sublexical phonological access over a quicker visual access, it is because it is more efficient and faster for them. Historically, two versions of the ODH have been offered: According to the strong ODH, readers of shallow orthographies perform a phonological analysis of the word based only on grapho-phonemic correspondence. This position has proved to be insufficient to account for pronunciation, even in shallow orthographies like Spanish or Serbo-Croatian, as lexical knowledge is always somehow needed for example to pronounce syllable stress that is not represented in written language. Given the lack of validity of the strong version of the ODH, a weaker version has been proposed in the literature. According to this version, all alphabetic orthographies may assemble phonology prelexically, but shallow orthographies should do so more than deep orthographies, because prelexical phonology is more readily available in these orthographies. This weak version is currently referred to as the ODH in the literature.

2.5.2.6 A Connectionist Model of Arabic Reading

The previous symbolic models inspired by dual-route models seem to be a narrow framework to understand Arabic reading, especially in its most commonly used phonologically incomplete undiacritized form. In this context, the phonological route is less useful than in more shallow orthographies, while the direct lexical route does not explain by itself the whole word-recognition process. Because of Arabic's deep orthography, readers of Arabic have significantly fewer phonological resources than readers of Latin alphabets. Therefore, they need to rely on other linguistic resources such as orthographic or morphological processes to be able to decode even isolated words.

Connectionist models provide a useful theoretical framework in such a case, to understand how Arabic reading really takes effect. As discussed, according to connectionism, codes are not accessed, they are computed. For instance, orthography can partially activate phonology, and phonology can partially activate meaning. The meaning of a word is therefore built up by means of activation from both routes, phonological and lexical, rather than accessed by means of the route that is most efficient for this particular word. Within this context, Hansen (2014*)* proposed a connectionist model of word-recognition in Arabic, inspired by the original connectionist word recognition model by Seidenberg and McClelland (1989). Hansen's proposed model is schematized in figure 2.8.

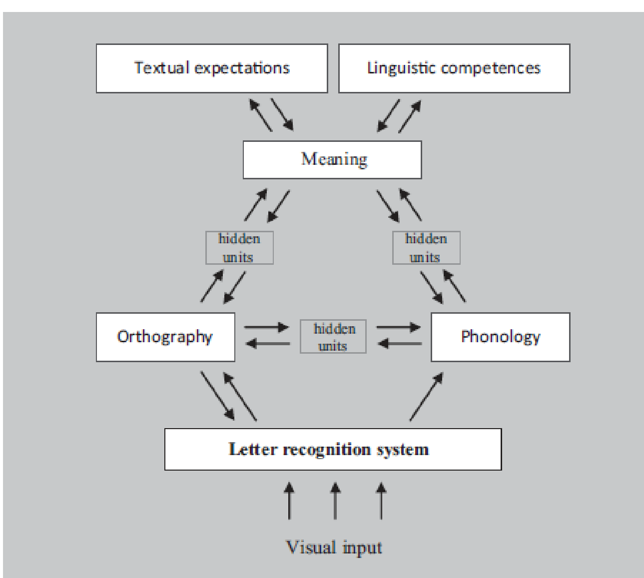

Figure 2.8: A word recognition system in Arabic (Hansen, 2014).

In accordance with connectionist theory, a continuous interplay between orthographic and phonological processes occurs, within which relevant resources established through previous exposure are activated. Morphology (roots and patterns) influence the reading process as one of the linguistic competences, and at the level of word recognition where it compensate for the missing vowels. Morphology is not explicit in the model but is internalized in the hidden units; in particular between orthography and phonology. That is, given the limited number of possible patterns for a certain letter string, the reader is left with a limited number of possible word structures stored in the hidden units to guide reading. In reading aloud, an articulated output can be added from the "phonology" box to external speech organs. Therefore, part of the information flow escapes this part of the model, which explains the documented weak connection between comprehension and reading aloud (Abu-Rabia, 1997). Compared to English, the information flow is more skewed toward the left in Arabic, as word recognition is more orthographic and context is more used for reading.

2.5.2.7 The Triliteral/Quadrilateral Root Model of Arabic Skilled Reading

Based on the important finding that (silent) reading comprehension, and reading aloud do not correlate (Abu-Rabia, 2001), Abu-Rabia (2002) suggested a reading model of undiacritized Arabic in which the two processes rely on different resources. The suggested model is schematized in figure 2.9.

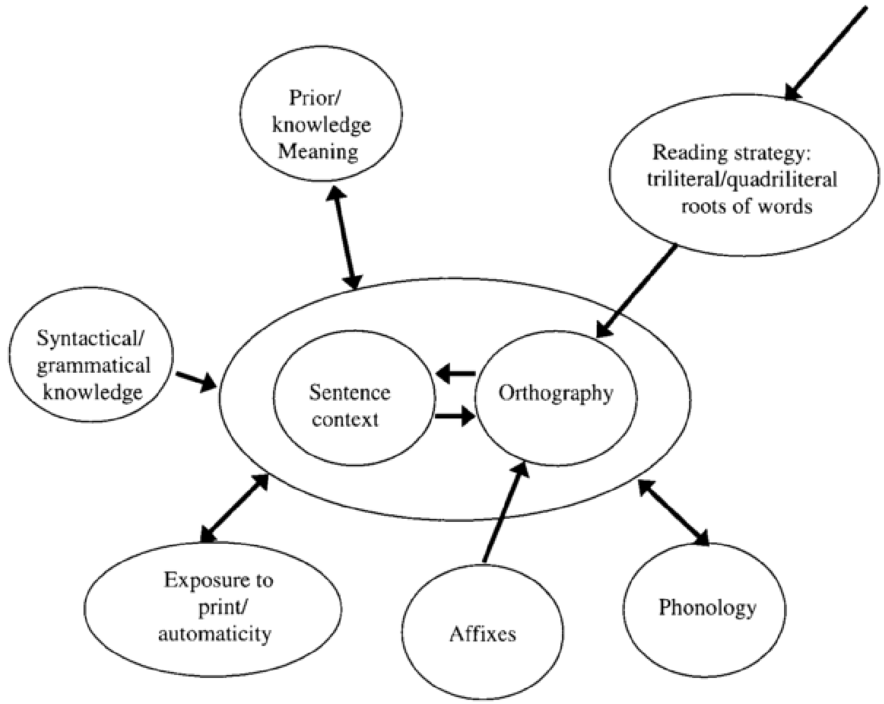

Figure 2.9: The Triliteral/Quadrilateral Root Model of Arabic Skilled Reading (Abu-Rabia, 2002).

According to this model, readers visually-orthographically identify the morphology of words (triliteral/quadriliteral root) to understand what they read, while they rely more on syntax and phonology to read accurately. That is, when reading silently, the readers' eyes identify the triliteral/quadrilateral roots that give a general meaning of the word and an understanding of the gist of the sentence, but they do not need the exact phonological and syntactic information that is needed for reading aloud.

3 EXPERIMENTS 1-2 - DO DIACRITICS CONTRIBUTE TO READING COMPREHENSION IN ARABIC?

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3.1 Introduction

Arabic presents a unique medium to examine how reading is processed when written material conveys either full or partial phonological information. As explained elsewhere in this thesis, written words in everyday Arabic reading are usually presented as mainly consonantal structures specifying few vowels. Vowel information is essentially provided by additional diacritical marks placed below or above the body of the words. Ordinarily, readers of Arabic use this opaque writing system in which the diacritical markers are missing. The main exceptions are liturgical texts and children's books, in which diacritics appear in order to help children to learn to read words during the first 4–6 years of primary school education. In the absence of diacritics, approximately one in three words in a typical passage of text is likely to have at least two different pronunciations that are associated with two different meanings (Abu-Rabia 1997, 1998). Depending on the superimposed vowels, the same string of letters represents phonologically and semantically distinct words (e.g., the string كتب */ktb/* can refer to كَتَبَ */kataba/ wrote,* كُتِبَ */kutiba/ was written,* كُتُب */kutub/ books).* Words of this kind are known as *heterophonic homographs* or *heterophones* and include nouns, verbs and conjunctions. As such, a word is considered unambiguous or homophonic if its undiacritized form has only one possible pronunciation when diacritized. It is considered ambiguous or heterophonic, when its undiacritized form is associated with two or more phonological pronunciations when diacritized. Heterophonic homographs also exist in other alphabetic orthographies (e.g. *a tear* in English), but they are considerably more common in Semitic orthographies such as Arabic and Hebrew. As Ibrahim, Eviatar, and Aharon-Peretz (2002) pointed out, the ambiguity of heterophonic homographs can only be resolved with reference to the context in which they appear (e.g., in English: *he had a tear in his eye; he had a tear in his shirt*).

Several scientific studies of Arabic have investigated the extent to which readers are affected by the presence or absence of diacritics. There is evidence that diacritics increase reading times. For instance, Bourisly, Haynes, Bourisly, and Mody (2013) found that diacritical markers slowed down lexical decisions about Arabic words regardless of how common the word was in the language (word frequency). Abu-Leil, Share, & Ibrahim (2014) and Ibrahim (2013) also showed that the presence of diacritics slowed down naming of written words by skilled and by developing readers respectively.

Nevertheless, the work of Abu-Rabia (1996, 1997, 1998) revealed that the presence of diacritical markers increased the accuracy with which single words and paragraphs were read aloud by both skilled and less skilled readers of Arabic. Subsequently, he showed that diacritics improved the ability of school students to answer comprehension questions about passages that they had read (Abu-Rabia, 1999). Moreover, Abu-Rabia (2001) investigated the influence of diacritics and sentence context on reading accuracy and comprehension among skilled adult readers of Arabic. Results showed that both diacritical markers and sentence contexts improved accuracy and comprehension across all reading conditions. As one might expect, a sentence context proved particularly helpful when words were presented without diacritics. For further details and a review of these studies, see Abu-Rabia (2002). More recently, Abu- Leil et al. (2014) showed that the presence of diacritics significantly improved the ability of skilled developing readers to answer comprehension questions about short passages of text.

Although previous research (e.g. Abu-Rabia, 2002) has shown that the presence of diacritics facilitates comprehension by adult readers of Arabic, it has not yet established precisely why this is the case. Experiment 1 attempted to investigate the reasons why diacritics might improve comprehension. One function of diacritics in Arabic is to indicate the syntactic role of words (for further details, see Saiegh-Haddad & Henkin-Roitfarb, 2014). This is because the ending of a word is diacritized according to its grammatical function in written sentences. Although it would appear possible that diacritics make syntactic processing easier for readers of Arabic, the diacritization of word-endings is not directly relevant to the experiments reported in this study and will not be addressed further. This study will instead focus on the fact that Arabic becomes a less transparent writing system when the diacritical markers are missing. In the absence of diacritics, approximately one in three words in a typical passage of text in Arabic is likely to have at least two different pronunciations that are associated with different meanings (Abu-Rabia, 1997).

To date, the effects of diacritics on the disambiguation of heterophonic homographs when reading Arabic have not been studied directly. The aim of Experiment 1 was to investigate whether the beneficial effects of diacritics on reading comprehension (e.g. Abu-Rabia, 2001) are specific to heterophonic homographs. If so, diacritics should make it easier for readers to access the appropriate meaning of ambiguous consonant sequences but have no effect on the comprehension of unambiguous words. The experiments also measured the speed with which semantic decisions were made. Adult readers of Arabic rarely encounter written words that are accompanied by diacritics, and so the undiacritized form of a word will often be more familiar than its fully diacritized version. The diacritized form is also more visually complex. Even if it improved accuracy, therefore, the presence of diacritics is likely to increase response times for both ambiguous and unambiguous written words (e.g. Abu-Leil et al., 2014; Bourisly et al. 2013).

In Experiment 1, participants made decisions about whether a visually presented word had a living meaning. They were asked to respond “yes” when a written word had a living meaning even if it also had a non-living meaning. The key interest is whether the presence of diacritics would improve the accuracy of responses to heterophonic homographs; would diacritical markers increase the probability that the living meaning of an ambiguous written word would be accessed when a semantic decision was being made? Such a finding would suggest that it is sometimes difficult, even for skilled readers of Arabic, to access the appropriate meaning of an ambiguous word when it is written without diacritics.

Some previous research (e.g. Abu-Rabia & Siegel, 2003; Taouk & Coltheart, 2004) suggested that computational dual-route models of reading can be applied to Arabic. In terms of the DRC model (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001), familiar words that are written without diacritics in Experiment 1 will be processed by the lexical-semantic route. In terms of the triangle model (e.g. Plaut, McClelland, Seidenberg, & Patterson, 1996) familiar words that are written without diacritics will be processed by the orthographic-semantic reading route. According to both models, the meaning of an unambiguous familiar written word should become available in the semantic system and a correct decision made on the semantic decision test.

The situation is more complex with ambiguous words. Folk and Morris (1995) found that English heterophonic homographs took longer to read than homonyms, and argued that this result provided evidence that both meanings of heterophonic homographs are automatically activated during reading. Gottlob, Goldinger, Stone and Van Orden (1999) suggested that, typically, one of the forms of a heterophonic homograph is dominant. The dominant meaning of the word is the one that is most strongly associated with the written form of the word. Gottlob et al. argued that even if both meanings are initially activated when a word is read, the more dominant meaning will inhibit the less dominant meaning. Consequently, readers will typically use the meaning of the more dominant form when deciding what the word means and ignore the less dominant meaning. In Hebrew, Bentin and Frost (1987) suggested that the dominant form of a heterophonic homograph is automatically activated first on a written-word naming task when the words are presented without diacritics. If these findings can also be applied to Arabic then, on trials when the non-living meaning of an ambiguous word is the dominant version of the homograph, participants may respond incorrectly that the word does not have a living meaning.

It is accepted (e.g. Saiegh-Haddad & Geva, 2008; Abu-Leil et al., 2014) that phonological processing of ambiguous written words in Arabic is likely to be facilitated by the presence of diacritics. When accompanied by diacritics, ambiguous words could therefore be read via the non-lexical (Coltheart et al., 2001) or phonological reading route (Plaut et al., 1996). This would allow the reader to generate a representation of the full phonological form of the word by activating the phonemes that are associated with each of the letters and diacritics that it contains. The phonological form of the word could then be used to access its associated meaning in the semantic system. The outcome would be a more accurate response on the semantic task when diacritics are present. There should be little or no effect on the accuracy of decisions about familiar unambiguous words because the appropriate semantic representation should be activated by the lexical/orthographic-semantic reading route regardless of the presence of diacritics.

It should also follow that there will be more errors on the semantic decision task when the living meaning of a homograph is the less dominant meaning. Therefore, pilot data about the dominance of the meaning of each of the homographs was collected, and the relationship between meaning dominance and performance on the semantic decision task was subsequently examined.

A quite different outcome is also possible in Experiment 1, however. It may be the case that diacritics facilitate the identification of any word that is otherwise difficult to identify regardless of whether or not it is a heterophone. Such an outcome would be consistent with Koriat's (1985) study of the effects of diacritics on word recognition in Hebrew. Koriat found that diacritical markers improved accuracy on a visual lexical decision task for low-frequency words only. The presence of diacritics was less helpful in the recognition of high-frequency words. Koriat's findings suggest that diacritics might aid the recognition of any word (such as low frequency words) whose written form is otherwise difficult to identify. In terms of the DRC and triangle models of reading, it should be relatively hard to access the meaning of such words via the lexical-semantic/orthographic-semantic reading route. For the reasons discussed earlier, when the word is presented with diacritics, it might be possible instead to generate the spoken form of the word via the nonlexical or phonological reading route. The meaning of the word could then be accessed and a correct response made on the semantic decision task. If this is true, then diacritics will be associated with improved performance on the semantic decision task regardless of whether or not the word is ambiguous. A critical issue for this study, therefore, is whether the presence of diacritics improves the accuracy of semantic decisions for all words or only semantic decisions for words that are heterophonic homographs.

3.2 Experiment 1

3.2.1 Method

3.2.1.1 Participants

The size of the sample was determined based on previous relevant literature (e.g., Folk and Morris, 1995; Frost and Bentin, 1992; Abu-Rabia, 2012). The participants were 50 undergraduate students from the Lebanese University in Beirut.who volunteered to take part in the study and signed a consent form approved by the University of Essex prior to performing the experimental tasks. Their ages ranged for 18–26 years. 25 were males and 25 females. None of the participants had experienced difficulties at school or suffered from neurological, emotional, attentional, or learning disorders. The participants were all bilingual native Arabic speakers. Although they were pursuing their university studies in their second language (English or French), they were only included in the study if they had been taught to read in Arabic at primary school and had a Lebanese high school degree (Baccalaureate). This is significant because many of the subjects that are studied as part of the curriculum for the Lebanese Baccalaureate involve reading in Arabic. Consequently, the participants were all proficient readers of Arabic.

3.2.1.2 Materials

Two pilot studies were conducted prior to the main experiment to establish the final set of stimuli. A preliminary 236-word list was initially created. All chosen words were nouns that contained between three and six letters. One half of the words represented living things, and the other half represented non-living things. Of this list, 52 words were ambiguous and the rest were unambiguous. A printed word was considered ambiguous if its written form was associated with phonologically and semantically different words when written without diacritics, one with a living meaning and one with a non-living meaning. For all of the words, the diacritics provided information about the identity of the vowels (e.g. عالم */ʕaːlm/* which is associated with two different diacritized words عَالِم */ʕaːlim/ scientist* and عَالَم */ʕaːlam/ world*). Occasionally a diacritic also provided information about germination (e.g., حمام */ħmaːm/* which is associated with two different words, حَمَّام */ħammaːm/ toilet,* and حَمام */ħamaːm/ pigeon).*

The first pilot study was designed to estimate the subjective familiarity of this pool of written words. 10 participants who had the same characteristics as the main experiment's participants were asked to rate on a scale of one to five how familiar they felt each of the 236 initial written word forms to be. Words were presented with the defining article al (equivalent to *the* in English) to prevent any confusion between verbs and adjectives. All words were presented with diacritics, and the two forms of ambiguous words were presented.

A second pilot study was designed to give an estimate of the dominance or availability of each meaning of the ambiguous words. Availability of a meaning refers to whether or not a participant accesses that meaning from the word's written form. The pilot study was conducted on an additional 10 participants who also had the same characteristics as the main experiment's participants. They were asked to define the 52 ambiguous nouns. The chosen nouns all had only two corresponding meanings when read with diacritics, one living meaning and one non-living meaning. The participants were first shown the words without diacritics and were asked to give one definition for each of the ambiguous written words; their responses were rated as the first availability of the word and could be either living or non-living. They were then shown the same list of written words, and were asked to provide another meaning of the word if applicable; the responses were rated as the second availability of the unambiguous word. The number of participants who provided the living meaning of the ambiguous word as their first response was used as the measure of availability. All words that had only one prominent meaning, as indicated by the fact that seven or more participants out of 10 were unable to give them more than one definition, were eliminated from the experiment. Forty critical ambiguous words from the initial 52 words were selected for use in the main experiment.

Two equivalent lists of written words, list A and list B, were then created for use in the main experiment. Each list contained 80 words, half of them with living meanings. Each list contained 20 of the 40 critical ambiguous words that had a living meaning (20) when presented without diacritics. The remaining 60 words (20 living and 40 non-living) on each list were unambiguous when presented without diacritics. Each of the ambiguous living words on list A was matched with another ambiguous living word on list B for length, familiarity, and dominance. Independent t tests showed that there was no difference between the words on list A and B in level of familiarity, $t(38) = .26$, $p > .05$, length, $t(38) = .01$, $p > .05$, or dominance, $t(38) = .04$, $p > .05$. Examples of the words are given in Table 1.

Ambiguity was due to lack of information about gemination in two of the ambiguous words, and to both gemination and absence of vowels in 13 additional words. In all of the other words, ambiguity was entirely caused by absence of vowels. Because of the limited number of ambiguous words that were suitable for use in the experiment, it was not possible to match the ambiguous and unambiguous words for familiarity and length. The critical analyses therefore compared: (i) the accuracy and the speed of responses to ambiguous words presented with and without diacritics; (ii) the accuracy and the speed of responses to unambiguous words with a living meaning presented with and without diacritics. The 80 words with non-living meanings were used as fillers and the responses to these words were not analyzed for either speed or accuracy.

In the main experiment, two similar final sets of words were constructed, set x and set z. Each set contained the same 160 written words, but set x comprised the words of list A presented with diacritics, and the words of list B presented without diacritics. Conversely, set z comprised the words of list A presented without diacritics, and the words of list B presented with diacritics. In summary, therefore, each final set of words contained:

- 20 ambiguous words with living meanings, presented with diacritics
- 20 ambiguous words with living meanings, presented without diacritics
- 20 unambiguous words with living meanings, presented with diacritics
- 20 unambiguous words with living meanings, presented without diacritics
- 40 unambiguous words with non-living meanings, presented with diacritics
- 40 unambiguous words with non-living meanings, presented with without diacritics

living ambiguous undiacritized	**living ambiguous diacritized**	**Non-living undiacritized**	**Non-living diacritized**
السلق	السِلْق	العراء	العَرَاء
المدرسة	المُدَرِّسَة	الطب	الطِب

Table 3.1: Examples of words used in Experiment 1.

3.2.1.3 Apparatus and Procedure

The experiment was written in E-Prime. The stimuli were presented on an HP Pavilion g6 laptop in a different random order for each participant. The words were displayed in a black Arial size-66 font on a white screen. Response latencies were measured to the nearest millisecond. The participants were tested individually. They sat about 50 cm from the monitor and used both their hands to answer. All the participants were presented with two similar 160-word lists (set x and set z). Half of the participants were presented with set x followed by set z, and the remaining participants were presented with set z followed by set x. Therefore, each participant saw all the 160 words in two forms, once with and once without diacritics. At the beginning of each trial, a fixation cross was presented in the center of the screen for 2 seconds. Then the first word appeared in the center of the screen. The word remained on the screen until the participant pressed one of two keys on the computer keyboard. The participants were instructed to press the F key if the word that appeared could represent a living thing, or to press the J key if it could not represent a living thing. They were asked to make their responses as quickly and as accurately as possible. Participants performed 8 practice trials which did not appear in the experimental trials.

3.2.2 Results and Discussion

Statistical analyses were conducted on the responses to the 80 words with living meanings. Two-way analyses of variance (ANOVAs) were performed on the mean number of ambiguous words accurately identified as having a living meaning, and on the mean reaction times (RTs) for accurately identified ambiguous words. The two factors were diacritics (presence versus absence of diacritics), and presentation (first presentation versus second presentation) and were both within-subject factors. Separate ANOVAs examined the effect of diacritics on accuracy and the RTs for unambiguous words. Effect sizes were calculated using Cohen’s d. Performance is summarized in Figs. 1 and 2.

Ambiguous Words

There was a significant main effect of the presence of diacritics on the accuracy scores for ambiguous words, $F(1, 49) = 155.18$, $p < .0001$, *effect size* = 3.0. Responses were more accurate when words were presented with ($M = 34.3$, $SD = 2.8$) than without diacritics ($M = 27.4$, $SD = 3$).

There was no significant difference between overall performance on the first and second presentation ($F < 1$), but the interaction between presence/absence of diacritics and first/second presentation condition was significant, $F(1, 49) = 7.92$, $p = .007$. Tests of simple main effects were performed to investigate this interaction further. They revealed a significant main effect of the presence of diacritics on the accuracy of responses to ambiguous words during both the first presentation, $F(1, 49) = 148.1$, $p < 0.001$, *effect size* = 2.1, and second presentation, $F(1, 49) = 38.0$, $p < 0.001$, *effect size* = 0.7. The interaction appears to have come about because the effect of diacritics on ambiguous words was larger on the first than on the second presentation. There was no main effect of diacritics on RTs for ambiguous words ($F < 1$). The effect of study phase on RTs just failed to reach significance, $F(1, 49) = 3.88$, $p = .06$. The interaction between the presence of diacritics and study phase was not significant ($F < 1$).

Unambiguous Words

There was no significant effect of the presence of diacritics on the accuracy of responses to unambiguous words, ($F < 1$). There was, however, a significant main effect of the presence of diacritics on RTs to unambiguous words, $F(1, 49) = 7.51$, $p < .01$, *effect size* = 0.3. On average, participants had longer reaction times to words presented with (*M* = 1542 ms, *SD* = 504) than without diacritics (*M* = 1369 ms, *SD* = 304).

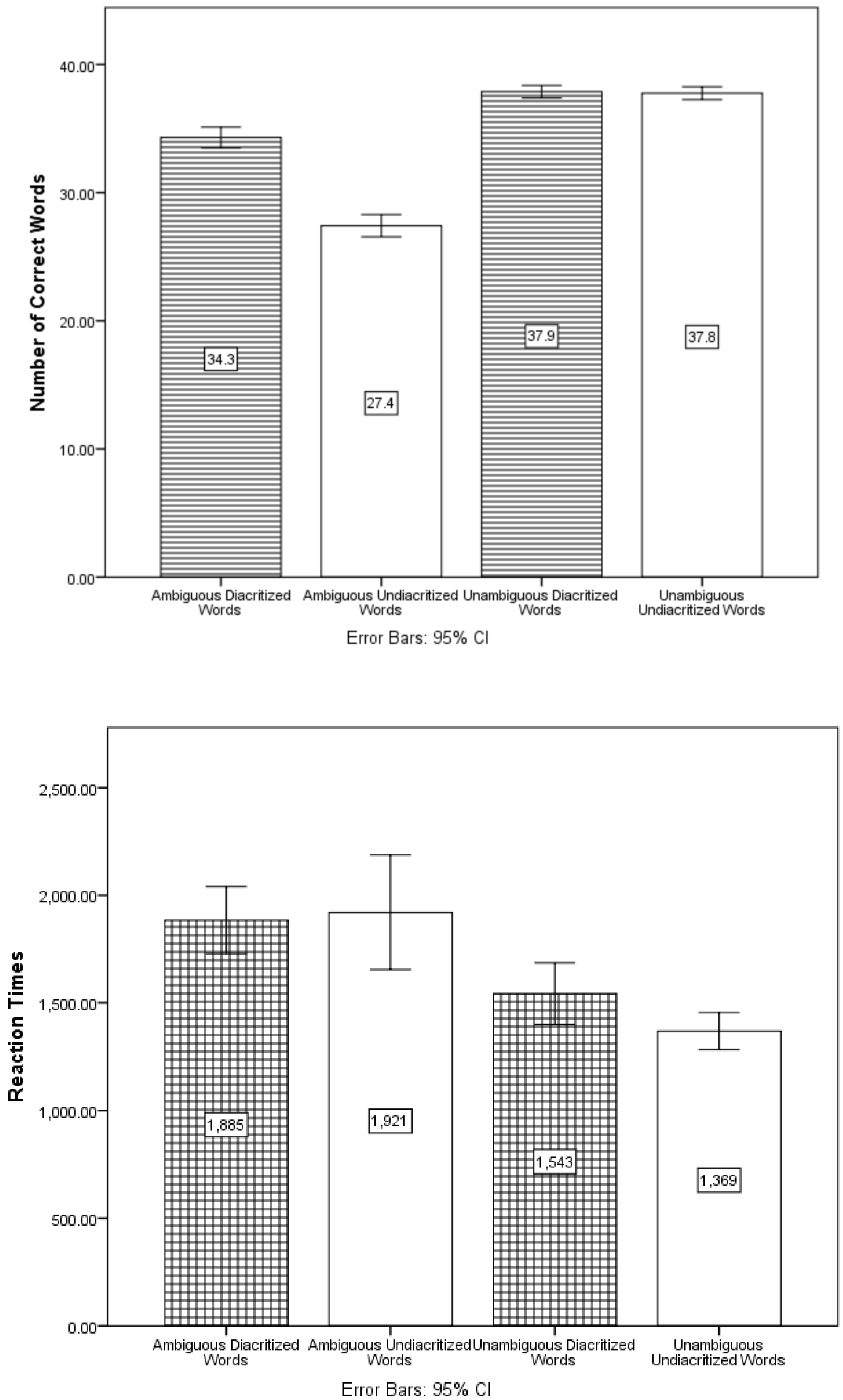

Figure 3.1: The effects of diacritics on the speed and the accuracy of single word comprehension in Experiment 1.

Effects of Familiarity and Dominance

Table 3.2 presents a correlation matrix that shows the relationship between the speed and accuracy of the responses to ambiguous words and the ratings of the familiarity and meaning dominance of each word. First availability refers to the probability that the first definition that participants gave to an ambiguous word during the pilot study had a living meaning. First availability was significantly correlated with both accuracy and speed; ambiguous words where the living meaning was the dominant meaning were associated with significantly higher accuracy in the presence and in the absence of diacritics. Ambiguous words where the living meaning was the less dominant meaning were associated with significantly lower accuracy in both the presence and absence of diacritics. Ambiguous words where the living meaning was the dominant meaning were associated with significantly shorter RTs when the words were presented with diacritics. The familiarity of an unambiguous word was not significantly correlated with either the speed or accuracy with which it was processed.

	Accuracy with diacritics		**Accuracy without diacritics**		**RT with diacritics**		**RT without diacritics**	
	r	*p*	*r*	*p*	*r*	*p*	*r*	*p*
Familiarity	.229	.155	.212	.189	-.063	.700	-.224	.164
1st availability	.510	.001	.811	.000	-.541	.000	-.224	.164

Table 3.2: Correlations between the familiarity and the meaning dominance of ambiguous words and the accuarcy and speed of the participants on the word's first presentation in Experiment 1.

Additionally, the effects of diacritics were further studied by calculating the difference in scores (accuracy and reaction times) between words when they were diacritized vs. when they were undiacritized on the first presentation. This difference was termed as the effect of diacritics; it represented the change in performance after the addition of vowels. Correlation between the effect of diacritics and the dominance (first availability) of the words indicated that the effect of diacritics on accuracy scores and the first availability of the word were negatively correlated, r (40) = -.67, $p <$ .001, while the effects of diacritics on reaction times and the first availability were not correlated r (40) = .28, p = .08. These results suggest that diacritics have an impact mainly on the subordinate meaning of the word by making it more readily available to the reader. Further analysis on how diacritics impact reading comprehension with relation to meaning bias will be conducted in Experiment 3.

The results of Experiment 1 have provided further evidence that skilled adult readers of Arabic are more accurate at comprehending written words when accompanied by diacritics. It appears that readers were not always able to access both meanings of written words that were ambiguous when presented without diacritics. Participants clearly knew many of these meanings because they performed significantly more accurately when the words were fully diacritized. It appears that participants were able to access the appropriate meaning when the presence of diacritics made it possible to generate the full phonological specification of the word, mainly for the subordinate meaning of the word. This outcome is consistent with the account outlined in the Introduction whereby the appropriate meaning of these words could be accessed indirectly via the non-lexical (Coltheart et al., 2001) or phonological reading route (Plaut et al., 1996). The significant correlation between accuracy and meaning dominance suggests that many of the incorrect responses to ambiguous words occurred when participants found it difficult to access the less dominant meaning of heterophonic homographs. This correlation was observed in both the presence and absence of diacritics. It was even clearer when the effect of diacritics on the accuracy scores was investigated. Significant effects of the presence of diacritics on accuracy were not observed when the words were unambiguous. There was therefore no evidence that diacritics had a facilitatory effect on participants' ability to recognize the visual form or access the meaning of unambiguous words. In fact, diacritics increased the amount of time that participants required in order to make decisions about unambiguous words. The beneficial effects of diacritics in this experiment were therefore specific to the processing of heterophonic homographs. The presence of diacritics significantly increased the accuracy of semantic decisions about the meanings of ambiguous words but had no significant effect on reaction times. Diacritics had no significant effect on the accuracy of semantic decisions about unambiguous words but produced significantly longer response latencies.

3.3 Experiment 2

An important issue is whether the increased accuracy that was observed when ambiguous words were presented with diacritics occurs only when single words are being processed. The results would be more striking if effects of diacritics could also be observed in a task that involves reading words in sentences. This is because reading generally takes place in the context of sentence processing rather than single word processing, and so the experimental task would draw more closely on processes involved in normal reading. Hence, the processing of ambiguous Arabic words when they were embedded in a sentence was examined in Experiment 2.

3.3.1 Method

3.3.1.1 Participants

The sample of the size was determined in reference to Experiment 1. The participants were 50 undergraduate students drawn from the same population as Experiment 1. None of them had participated in Experiment 1. 25 participants were male and 25 females. All signed an informed consent before participating in the experiment.

3.3.1.2 Materials and procedure

Participants were shown 160 sentences one at a time and had to decide whether each sentence was meaningful. A separate sentence was constructed for all of the 160 words shown in the first experiment. The sentences were constructed so that they would be meaningful if the word had a living meaning (e.g. tiger in the sentence “The tiger attacked its prey”), and meaningless if the word had only a non-living meaning (e.g. room in the sentence “The room sat on the teacher”). When written with diacritics, the form of ambiguous words was always consistent with the living meaning of the word. Therefore the sentences that were generated for ambiguous words were always meaningful. This means that participants should always respond affirmatively to sentences containing an ambiguous word. A sentence would appear to be meaningless, however, if a participant could access only the non-living meaning of an ambiguous word. Half of the sentences were presented with diacritics and half were presented without diacritics. In addition to the phonemic diacritization on the word found in Experiment 1, morpho-syntactic diacritization was added to the ending of the words, as it is usually indispensible in sentence-writing.

As in Experiment 1, participants were divided into two groups. Half of them saw words from set x and half saw words from set z. Both groups saw exactly the same sentences but differed in terms of which sentences they saw with and without diacritics. In set z, the sentences that had been presented without diacritics in set x were presented with diacritics, and the sentences that had been presented with diacritics in set x were presented without diacritics.

To summarize, both set x and set z comprised:

- 20 meaningful sentences presented with diacritics containing an ambiguous word with a living meaning.
- 20 meaningful sentences presented without diacritics containing an ambiguous word with a living meaning.
- 20 meaningful sentences presented with diacritics containing an unambiguous word with a living meaning.
- 20 meaningful sentences presented without diacritics containing an unambiguous word with a living meaning.
- 40 meaningful sentences presented with diacritics containing an unambiguous word without a living meaning.

- 40 meaningful sentences presented without diacritics containing an unambiguous word without a living meaning.

The experiment was written in E-Prime. The stimuli were presented on an HP Pavilion g6 laptop in a different random order for each participant. The sentences were displayed in a black Arial size-66 font on a white screen. Response latencies were measured to the nearest millisecond. The participants were tested individually. They sat about 50 cm from the monitor and used both their hands to answer. At the beginning of each trial, a fixation cross was presented in the center of the screen for 2 seconds. Then the first sentence appeared in the center of the screen. The sentence remained on the screen until the participant pressed one of two keys on the computer keyboard. The participants were instructed to press the F key if the sentence that appeared was meaningful, or to press the J key if it wasn't. They were asked to make their responses as quickly and as accurately as possible. Participants performed 8 practice trials which did not appear in the experimental trials. Examples of sentences used in the experiment can be seen in Table 3.3.

living ambiguouswithout diacritics	**ذبل السلق المقطوف**
living unambiguous with diacritics	حَطَّ الحَمَامُ عَلَى النَافِذَةِ

Table 3.3: Examples of the sentences used in Experiment 2.

3.3.2 Results and Discussion

ANOVAs examined the effect of diacritics on the mean number of sentences correctly identified as meaningful, and on the mean reaction times (RTs) for accurately identified sentences. Separate analyses were conducted on ambiguous and unambiguous sentences.

Ambiguous Sentences

Accuracy scores were significantly higher on sentences containing diacritics (*M* = 17.5, *SD* = 2.2) than on sentences without diacritics (*M* = 16.2, *SD* = 2.8), $F(1, 49) = 14.35$, $p < 0.001$, *effect size* = 0.8. Participants also had significantly slower reaction times to sentences containing diacritics (*M* = 3057, *SD* = 1213) than to sentences without diacritics (*M* = 2678, *SD* = 754), $F(1, 49) = 10.02$, $p = .003$, *effect size* = 0.8.

Unambiguous Sentences

There was no main effect of the presence of diacritics on accuracy, ($F < 1$), but unambiguous sentences were read significantly more slowly with (*M* = 2547, *SD* = 916) than without diacritics (*M* = 2259, *SD* = 644), $F(1, 49) = 13.95$, $p < 0.001$, *effect size* = 0.3). The effects of diacritics on RTs and accuracy scores are summarized in Fig. 3.2.

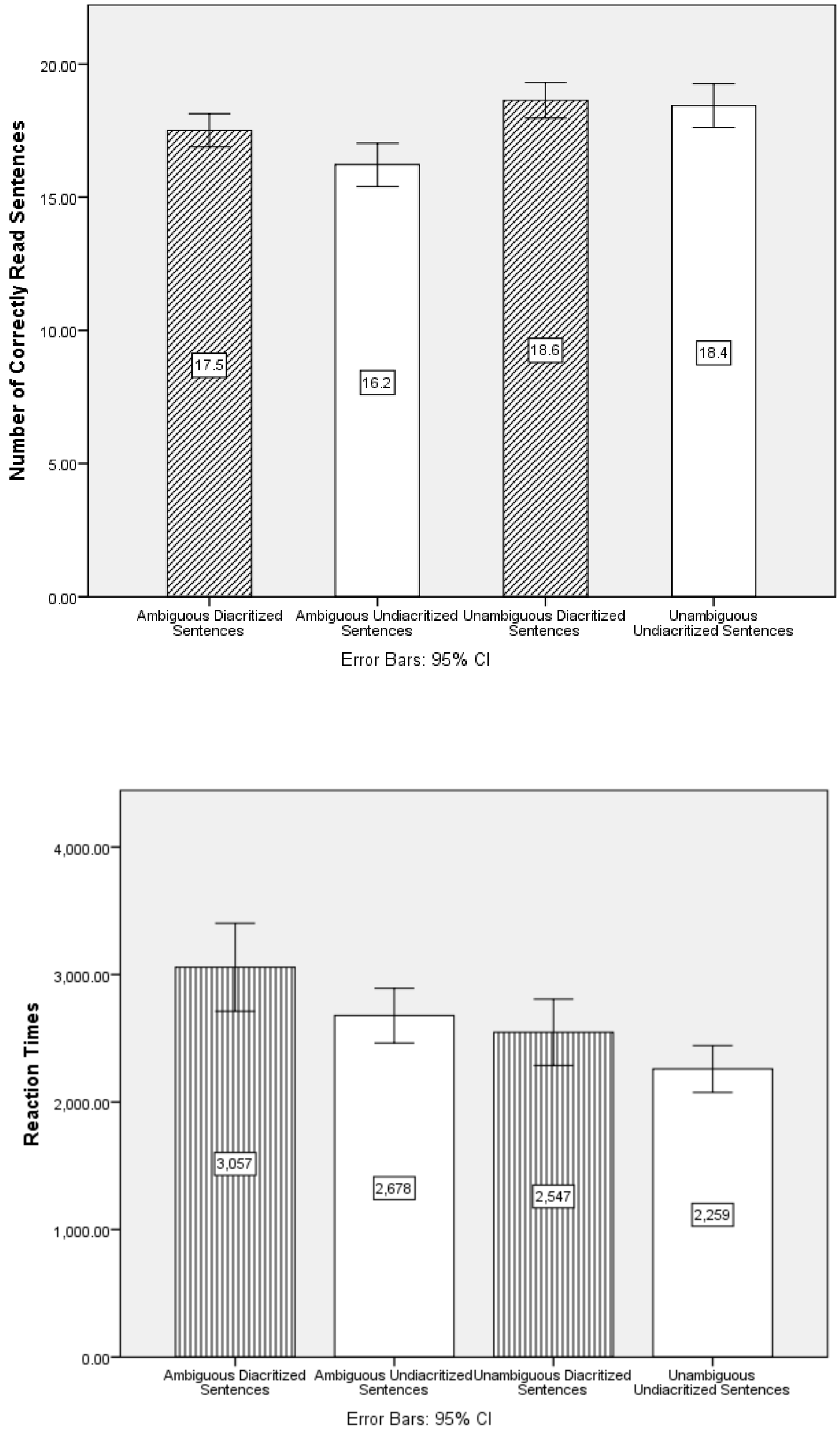

Figure 3.2: The effects of diacritics on the accuracy and the speed of sentence comprehension in Experiment 2.

Words and Sentences

The accuracy scores obtained from the first set of words presented in Experiment 1 were compared with the accuracy scores for sentences in Experiment 2 in two-way ANOVAs, with the type of item (word vs. sentences) as a between subjects factor, and the presence of diacritics as a within subject factor. Performance with ambiguous items and unambiguous items were examined in separate analyses.

Ambiguous items: There was a significant main effect of the presence of diacritics on the accuracy scores, $F(1, 98) = 128.03$, $p < .001$, *effect size* = 2.4, for all items containing ambiguous words. The effect of type of stimuli (words vs. sentences) on accuracy was also significant, $F(1, 98) = 14.02$, $p < .0001$, *effect size* = 1.3. On average, participants scored significantly higher when words were presented in a sentence ($M = 16.9$, $SD = 2.5$), than when shown as single words ($M = 15.4$, $SD = 1.95$). The interaction between diacritics and type of stimuli was also significant, $F(1, 98) = 35.82$, $p < .0001$ indicating that diacritics had different effects when they were added to words or to sentences.

Additional analyses were conducted to further investigate the nature of this interaction by examining how much adding diacritics changes the readers' performance. The effect of diacritics was calculated by subtracting performance on items with diacritics from performance on the same items without diacritics. Comparison between the effect of diacritics on words vs. sentences indicating that diacritics improved the comprehension of words ($M = 4.22$, $SD = 2.4$) significantly more than sentences ($M = 1.3$, $SD = 2.4$), $t(98) = 5.98$, $p < .01$, $d = 1.2$.

Unambiguous items: There was no significant main effect of the presence of diacritics $F(1, 98)$ 1.18, p = .28, or type of stimuli ($F < 1$), on the accuracy scores for unambiguous words. The interaction between these two variables failed to approach significance ($F < 1$).

The effect of diacritics was statistically smaller with sentences than with words. Presumably, this is because the additional contextual information sometimes activated the less dominant living meaning of an ambiguous word, and therefore diacritics were not needed anymore to disambiguate the phonology of the word. Nevertheless, consistent with results in Hebrew (Koriat, 1985), the meanings of heterophonic homographs were still processed more accurately with diacritics, even when they appeared in context. Conversely, the presence of diacritics had no effect on the comprehension accuracy of sentences that contained only unambiguous words. As reported in previous research, (e.g., Abu-Leil et al., 2014; Bourisly et al. 2013), reaction times were significantly longer when sentences contained diacritics whether they comprised an ambiguous or an unambiguous word. This observed response delay with the addition of diacritics might reflect the slower assembled route used by the reader when encountering such a shallow orthography (For a discussion in Hebrew, see Frost, 1994). It might be also that because diacritics provide additional visual information, they are processed more slowly by readers (Roman & Pavard, 1987; Hermena et al. 2015).

3.4 Discussion of Experiments 1 and 2

Previous research (e.g. Abu-Rabia, 2001) revealed evidence of improved comprehension by skilled adult readers of Arabic when written words were accompanied by diacritics. The results of the two experiments reported in this study have extended these findings by discovering a cause of the facilitatory effects of diacritics. The findings revealed that diacritics had no effect on participants' ability to access the meaning of unambiguous words; the beneficial effects of diacritics were confined to the processing of heterophonic homographs. This is an important finding because, as pointed out in the Introduction, a high proportion of Arabic words are ambiguous and heterophonic when written without diacritics. Because these effects were also observed when words were presented in grammatical sentences in Experiment 2, they are likely to occur during normal reading of heterophonic homographs rather than just in experimental tasks conducted in the laboratory.

It is interesting to compare the results with the effects of diacritization on the processing of heterophonic homographs that were observed in Hebrew by Bentin and Frost (1987). Bentin and Frost found that diacritization reduced the speed of lexical decision whereas the current study showed that diacritization improved performance on a task that required access to one specific meaning of a heterophonic homograph. The key difference is that, as Bentin and Frost argued, lexical decision does not require disambiguation whereas the living/non living task employed in this study cannot be performed accurately unless access to one specific meaning of a homograph has successfully taken place. Diacritization appears to improve the probability of access to the specific meaning of a homograph even though it may slow access to its lexical form in lexical decision tasks.

It is also interesting to note that recent research suggests that in Hebrew there are other tasks in which diacritization does not improve performance on heterophonic homographs. Vaknin-

Nusbaum and Miller (2014) recently showed that recall from short-term memory (STM) of heterophonic homographs, non-homographs and homophonic homographs in Hebrew was unaffected by whether the words were written with or without diacritics. STM performance is unlikely to be impaired if one meaning of an ambiguous word cannot be activated because recall from STM is unlikely to require disambiguation. Vaknin-Nusbaum and Miller's (2014) results are therefore consistent with the results of the present study; the beneficial effects of diacritics in Semitic orthographies occur when the experimental task requires access to a specific meaning of a heterophonic homograph.

Additionally, the current results suggest that when the dominant form of a homograph was associated with a non-living meaning, participants found it relatively difficult to access the word's living meaning and made an incorrect semantic decision as a consequence. As in English (e.g. Gottlob et al., 1999), these findings suggest that there is a tendency in Arabic for the less dominant form of a heterophonic homograph to be inhibited by the more dominant form when they are read without diacritics. These findings can be accommodated equally well by the triangle (Plaut et al., 1996) and the DRC (Coltheart et al., 2001) computational models of reading. One suggestion is that the presence of diacritics allows the full phonological form of the word to be generated by the non-lexical (Coltheart et al., 2001) or phonological reading route (Plaut et al., 1996). Processing of this kind will in turn often allow the appropriate meaning of an ambiguous word to be accessed in the semantic system as a consequence.

One advantage of presenting words without diacritics in Arabic is that word recognition appears to proceed more quickly once skilled readers have learnt to identify familiar words that are written without diacritics (e.g. Abu-Leil, Share, & Ibrahim, 2014; Bourisly et al. 2013). The investigation of response latencies in the current study produced a similar outcome. In Experiment

1, response times were significantly shorter when unambiguous words were presented without diacritics. In Experiment 2, both ambiguous and unambiguous sentences were processed more quickly when presented without diacritics. It is therefore clear from the investigations reported here that diacritization does slow down reaction times of skilled adult readers of Arabic. Nevertheless the results of the previous experiments show that diacritization increases the likelihood that readers will access the correct meaning of an ambiguous word. There is therefore a trade-off in the reading of Arabic in its undiacritized form between increased speed and reduced accuracy. It is hoped that in future researchers will devote more time to the study of reading in Arabic by investigating this trade-off in greater detail.

4 EXPERIMENT 3 - IS THERE AN OPTIMAL DIACRITIZATION FOR UNDERSTANDING WRITTEN ARABIC?

4.1 Introduction

In Experiment 1 and Experiment 2, the contribution of diacritics to understanding written Arabic was investigated by having participants decide whether a written word (with and without diacritics) has a living meaning, and whether a written sentence (with and without diacritics) is meaningful. The experiments looked at whether the presence of diacritics improves the comprehension of all written words, or whether it improves the comprehension of only heterophonic homographs (by disambiguating them phonologically). The results showed clearly that diacritics facilitate the comprehension of written heterophonic homographs (decreased error rate for diacritized words, without speed implications) while they hamper the processing of unambiguous words (slower reaction time, and same accuracy for diacritized and undiacritized words).

Following these conclusions, it seemed reasonable to assume that there may be a favorable condition for reading Arabic in which the trade-off between speed and accuracy is optimized. The logic is that if indeed diacritics only facilitate the comprehension of heterophonic homographs, then diacritizing only those types of words in a sentence might producethe best condition for reading comprehension. Adding diacritics to such critical words might make reading more accurate without at the same time slowing down the processing of the rest of the sentence. To evaluate this possibility, Experiment 3 compared how participants processed sentences when they were fully diacritized, undiacritized, or when only the ambiguous heterophonic homograph was diacritized in the sentence. This comparison was carried out to clarify which condition might be considered as the best for improved comprehension of written Arabic. With evidence from previous experiments, it seemed likely that the selectively diacritized condition would prove to be the most efficient condition. This is because selective diacritization would allow accurate processing of the homograph without slowing down the processing of the remaining unambiguous words of the sentence.

However, because Arabic readers are more familiar with the undiacritized script in their daily reading, they might find it difficult to process such an unfamiliar selectively diacritized script. As reported by Ibrahim (2013) and Abu-Leil (2014), skilled readers of Arabic typically rely on a direct whole-word encoding procedure, and the presence of diacritics even on a single word might delay reading instead of facilitating it by puzzling the reader who is not used to this kind of script. Thus, the selectively diacritized condition might prove to be ineffective after all.

Further, recent work (Hermena et al., 2015, 2016) has provided a fuller picture of the varying effects of diacritics on heterophonic homographs by suggesting that processing diacritics in those words is additionally modulated by the pattern of diacritization (dominant or subordinate), and by the readers' expectations for a particular pattern of diacritics (dominant or subordinate) on the word. That is, Hermena et al. (2016) showed that diacritization improved reading of heterophonic homographs only for the subordinate meaning and not the dominant one. By tracking eye-movements, they observed that when the readers did not detect the presence of diacritic ahead of time, they expected to see the dominant version, and so they took more time in reading (inflated gaze duration) the subordinate one. Further, when they previewed the diacritics, the readers took less time in reading the diacritized subordinate meaning, while no changes in gaze duration were reported for the preview of the dominant meaning. Hermena et al. (2016) proposed that this observed pattern of responses reflects the readers' expectations for the subordinate meaning when they identify the word as being diacritized. Recall that the subordinate meaning may be diacritized in everyday texts when the sentence context is not sufficient to disambiguate the heterophonic homograph, while the dominant pronunciation is typically left undiacritized (Schultz, 2004). As a result, when diacritics are perceived by the reader, they may be expected to belong to the subordinate meaning. Moreover, as pointed out in Experiment 1, the dominance of a word was positively correlated with its speed and accuracy of comprehension, and the effects of diacritics were even more important when they clarified the subordinate meaning of the heterophone.

Therefore, in addition to describing which condition is optimal for reading, the following experiment also aimed to learn how diacritization operates in such a presumably efficient condition. More specifically, an additional issue was to determine whether diacritization affects all phonologically ambiguous words (i.e. heterophonic homographs) equally, or whether the facilitating effect of diacritics is different for the dominant vs. the subordinate meaning of the word in a sentence. The relationship between the effect of diacritics and the dominance of the word was therefore also investigated. The prediction was that diacritization facilitates reading comprehension (improving accuracy without slowing the speed) mostly when it helps disambiguating the subordinate meaning of the word in the sentence.

4.2 Method

4.2.1 Participants

The sample of the size was determined in reference to Experiment 1. The participants were 48 undergraduate students who were all volunteers. All of them were Arabic native speaker. They all had a Lebanese high school degree (Baccalaureate), and could be considered as proficient in Arabic reading, as the Arabic language is widely covered in the Lebanese baccalaureate curriculum. Like the majority of Lebanese university students, they had all pursued their studies in a second language (English or French). They had not completed any university degree, and were enrolled in public health majors at the Lebanese University. Their ages ranged between 18 and 26 years. 13 were males and 35 were females. None of the participants had school difficulties or suffered from neurological, emotional, attentional, or learning disorder. All participants signed a consent form approved by the University of Essex prior to performing the experimental tasks. Ethical approval was granted by the University of Essex Science and Health Faculty Ethics committee.

4.2.2 Materials

Two sets of 20 experimental ambiguous sentences, set A and set B were constructed using the ambiguous words from list x and list z of Experiment 1. All sentences contained the target ambiguous words from experiment 1 used as a living subject in a sentence, such that the sentence would be meaningful if the word has a living meaning, and it would be meaningless if the word has a non-living meaning. The sentences were constructed in a way that only the ambiguous words of experiment 1 would be ambiguous; all the other words of the sentence were unambiguous.

The sentences were presented in three conditions: Fully diacritized, undiacritized, and selectively diacritized only the ambiguous word was diacritized. 40 diacritized/undiacritized/selectively diacritized meaningless sentences were used as non-experimental fillers. Their diacritization matched the experimental condition.

4.2.3 Apparatus

Superlab software was used to present the sentences in a random order. Sentences were presented in black Arial size-66 font on a white screen an on an HP Pavilion g6 laptop. Response latencies were measured to the nearest millisecond. The participants were tested individually. They sat about 50 cm from the monitor and used both their hands to answer. At the beginning of each trial, a fixation cross was presented in the center of the screen for 2 seconds. Then the first word appeared in the center of the screen. The word remained on the screen until the participant pressed one of two keys (J or F) on the computer keyboard.

4.2.4 Procedure

The experiment used a mixed design with the type of diacritization (selective or full) as a between subjects factor, and the presence of diacritization (present or absent) as a within subject factor. Participants were tested individually. They were divided in two groups of 24 participants each. The first group performed the task in the fully diacritized and undiacritized conditions: 12 participants read set A fully diacritized and set B undiacritized, while 12 others read set A undiacritized and set B fully diacritized. The second group performed the task in the undiacritized and the selectively diacritized conditions: 12 participants read set A selectively diacritized and set B undiacritized, while 12 others read set A undiacritized and set B selectively diacritized. The participants were instructed to look at a cross in the middle of the screen between stimuli, and to press the F key if the sentence they see is meaningful, or to press the J key if it is not meaningful.

4.3 Results

ANOVAs were performed on the mean number of sentences accurately identified as meaningful, and on the mean reaction times (RTs) for accurately identified sentences. Initially, two separate one-way ANOVAs were conducted: The first analysis was made on fully diacritized vs. undiacritized sentences and the second one on selectively diacritized vs. undiacritized sentences. Diacritization was considered as selective when only the ambiguous word was diacritized in the sentence.

Full diacritization

Mean scores are presented in Figure 1 (accuracy) and Figure 2 (RT). There was a main effect of diacritization on accuracy, $F(1, 23) = 7.03$, $p = .014$, and on reaction times, $F(1, 23) = 5.28$, $p = .03$. On average, participants had better accuracy scores with fully diacritized sentences ($M = 18.5$, $SD = 1.1$) than with undiacritized sentences ($M = 17.2$, $SD = 1.7$), and undiacritized sentences were read significantly quicker ($M = 2879$, $SD = 907$) than fully diacritized sentences ($M = 3148$, $SD = 1069$). These results indicate that fully diacritized sentences are better understood than undiacritized ones, but they are read more slowly. These findings are consistent with those reported in Experiment 1 and 2.

Selective diacritization

Mean scores are presented in Figure 1 (accuracy) and 2 (RT). There was a main effect of selective diacritization on accuracy, $F(1, 23) = 15.86$, $p < .001$. Participants understood sentences more accurately when they were selectively diacritized (M = 17.5, SD = 2.1) than when they were undiacritized (M = 16.1, SD = 1.9). Undiacritized sentences were read quicker (M = 2989, SD = 850) than selectively diacritized sentences (M = 3199, SD = 745), but this difference just failed to reach significance, $F(1, 23) = 3.34$, $p = .08$. The results suggest that the participants' accuracy improves when only the ambiguous word is diacritized in the sentence, while their speed is nearly identical.

Full and selective diacritization:

The previous analyses indicated that both full and selective diacritization improve reading comprehension, and make reading at least marginally slower, but they did not indicate whether this effect differs between the fully and the selectively diacritized condition. For the purposes of this study, a comparison of the readers' performance in the selectively and the fully diacritized conditions is particularly important to enhance our understanding of a possible optimal reading condition. To this end, a two-way ANOVA compared the accuracy and RTs of the responses to sentences when they were diacritized and undiacritized, with the type of diacritization (full, selective) as a between-subjects factor.

The results revealed that there was a main effect of diacritization on the accuracy scores, responses being overall more accurate when diacritized (M = 18.0, SD = 1.7) than not (M = 16.7, SD = 1.8), $F(1, 46) = 20.1$, $p < .0001$. The effect of the type of diacritization (experimental condition) was also significant, $F(1, 46) = 7.69$, $p = .008$, indicating that the participants assigned to the full diacritization condition were generally more accurate (M = 17.9, SD = 1.7) than those assigned to the selective diacritization condition (M = 16.8, SD = 1.8). The interaction between the presence and the type of diacritization was not significant however, $F(1, 46) = .043$, $p = .83$. The absence of a significant interaction indicates that the facilitating effect of diacritization is statistically the same whether the sentence is fully diacritized or when only the ambiguous word is diacritized in the sentence (see Figure 1). There was a main effect of diacritization on RTs, $F(1, 46) = 8.53$, $p = .005$, with diacritized sentences being read slower ($M = 3174$, $SD = 912$) than undiacritized sentences ($M = 2934$, $SD = 871$). There was no difference between the overall reading speed of the group that was assigned to the full diacritization condition ($M = 3014$, $SD = 816$), and the second group that was assigned to the selective diacritization condition ($M = 3094$, $SD = 832$), $F(1, 46) = .10$, $p = .74$. The interaction between the presence and the type of diacritization was not significant, $F(1, 46) = .01$, $p = .72$. The absence of an interaction means that the slowing effects of diacritization are equivalent regardless of whether the sentence is fully diacritized, or only the ambiguous word is diacritized in the sentence.

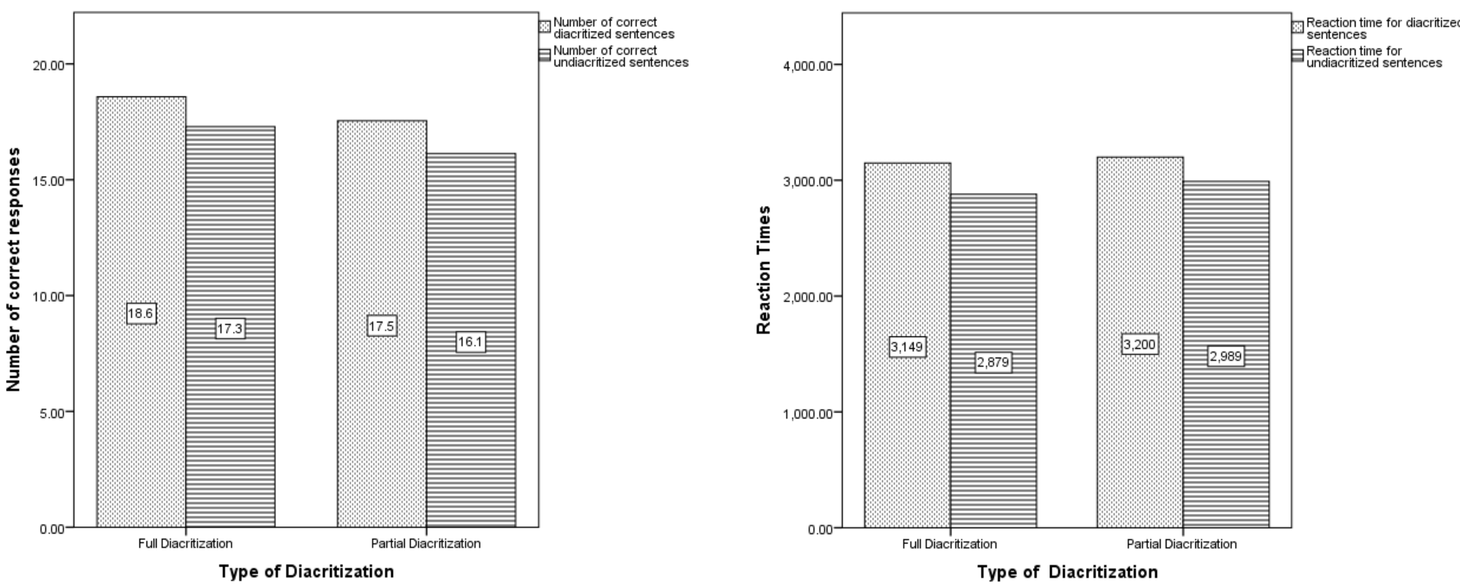

Figure 4.1: The effects of diacritics on the speed and the accuracy of reading comprehension depending on the type of diacritization in Experiment 3.

Relationship between Diacritics and Meaning Dominance

As with the analysis conducted in Experiment 1, the effects of diacritization on sentences containing different types of ambiguous words (i.e., conveying a more or less dominant meaning) were examined in order to determine if diacritization impacts ambiguous words uniformly or differently depending on the bias of their meaning (dominant or subordinate). To this end, a Pearson product-moment correlation coefficient was computed to assess the relationship between the dominance of the word and the effect of diacritization on its RT and accuracy scores. Additionally, the effect of diacritization reflected the change in performance after the addition of vowels; it was calculated by subtracting performance on diacritized sentences from performance on undiacritized sentences.

There was a negative correlation between the dominance of the ambiguous word and the effect of diacritization on the accuracy scores of its containing sentence in both the selective diacritization (r = -.45, p = .004, n = 40) and the full diacritization (r = -.52, p = .001, n = 40) conditions. The more dominant the meaning of an ambiguous word, the less it benefited from diacritics in order to be understood in a sentence. Conversely, there was no correlation between the dominance of the ambiguous word and the effect of diacritization on speed of recognition of its containing sentence in both the selective diacritization (r = -.10, p = .53, n = 40) and the full diacritization (r = .05, p = .74, n = 40) conditions. Therefore, there was no relationship between meaning dominance and reading speed.

The effects of diacritization on accuracy scores depending on the dominance of the word were further investigated by comparing the impact of diacritization on words having a dominant meaning to words having a subordinate meaning, by using 2-way ANOVAs in both the selective diacritization and the full diacritization conditions. The words were considered to have a subordinate meaning when the first availability rating of their living meaning ranged between 0 and 3. They were considered as balanced when ratings were equal to 4-5-6, and they were considered as dominant when ratings were 7 or more. Because 16 words had a subordinate meaning, 18 a dominant meaning, and 6 a balanced meaning, accurate answers were presented in an equivalent ratio form as a percentage of correct responses. Also, because only six words had a balanced meaning, performance on words that had a dominant meaning was compared to performance on words that had a subordinate meaning. Although this experiment was not designed to determine the varying effects of diacritization in relation to the dominance of the word, the following analysis might provide an interesting insight on how diacritics operate when they are added to a word in a sentence (whether the full sentence is diacritized or not). The following findings can provide direction to future research using matched word sets and appropriate methodology.

When only the heterophone was diacritized in the sentence, there was a significant interaction between the addition of diacritics and the dominance of the word on accuracy scores = $F(1, 23) = 15.1$, $p = .001$. On average, words did not gain from the addition of diacritics if they had a dominant meaning, while diacritization significantly improved comprehension of words having a subordinate meaning.

When the sentences were fully diacritized, there was also a significant interaction between the addition of diacritics and the dominance of the word on accuracy scores $F(1, 23) = 23.2$, $p < .0001$. Inspection of the means suggest that while adding diacritics made words with a subordinate meaning better understood, diacritization did not help access to the dominant meaning of the word.

Results are summarized in table 4.1.

	Selectively diacritized condition		*Fully diacritized condition*	
	Undiacritized	***Diacritized***	***Undiacritized***	***Diacritized***
Number of correct words with subordinate meaning (out of 16 words)	10.6 (2.6)	13.3 (2.5)	12.1 (2.5)	14.5 (1.5)
Number of correct words with balanced meaning (out of six words)	4.7 (1.2)	4.9 (1.2)	5.2 (1.3)	5.5 (1.6)
Number of correct words with dominant meaning (out of 18 words)	14.9 (1.6)	14.8 (1.6)	15.2 (0.8)	13.5 (2.4)

Table 4.1: Means and standard deviations of correctly understood sentences in the diacritized conditions of Experiment 3.

4.4 Discussion

Experiment 3 was designed to determine whether selectively diacritizing only the phonologically ambiguous words in an otherwise undiacritized sentence would prove to be the most efficient condition in understanding Arabic. That is, would it help the skilled Arabic adult reader to access meaning without losing any speed while doing so? Although the participants randomly assigned to the full diacritization condition surprisingly appeared to be overall more accurate than those assigned to the selective diacritization condition, a general pattern of results has emerged from Experiment 3. Adding diacritics to only the ambiguous word in the sentence seemed to facilitate reading comprehension as much as adding diacritics to the whole sentence. Results for reading speed were more mixed. Even though a comparison between the varying effects of diacritics did not reveal a difference between the fully diacritized and the selectively diacritized condition, a comparison of diacritized vs. undiacritized sentences in each condition independently showed that adding diacritics to the whole sentence slowed down reading while adding diacritics to only the heterophonic homograph in the sentence marginally affected reading speed.

Thus, contrarily to the initial hypothesis, there was no clear evidence from Experiment 3 that adding diacritics to a full sentence significantly delayed reading more than adding diacritics to the ambiguous word only. It is not certain why this is the case. One possibility is that the limited sample size did not allow the study to detect the effect of the type of diacritization on reading. Still, the previous data supports the proposition that although the extra visual processing brought by the addition of diacritics contributes to delaying reading in Arabic (Romand & Pavard, 1987, Hermena et al. 2015) it does not fully explain it. That is, although diacritizing the whole sentence considerably increases its visual complexity, Experiment 3 did not provide clear evidence that it slowed it significantly more than adding far less diacritics to just one word in the sentence. The data reported in this experiment did not offer further evidence on why diacritics impede reading speed. As was proposed by Taouk & Coltheart (2004), Ibrahim (2013) and Abu-Leil (2014), it might be that the addition of those unfamiliar signs directs the readers' attention toward phonology, and it impedes reading speed by inducing the use of an indirect assembled route instead of the more habitual and efficient direct assembled route. Alternatively, as suggested by Koriat (1984), it might be that because the sentence (in the selectively diacritized condition) contained diacritized words along with undiacritized ones, the readers tended to use the phonological route that is appropriate for words with diacritics for both the words that contained diacritics and those that didn't. Hence, there were no significant differences between processing selectively diacritized sentences and fully diacritized sentences.

Moreover, findings from eye-movement studies reported similar performance in fully diacritized and undiacritized sentences in contrast to an improved performance in the selectively diacritized condition (Hermena et al., 2015). Conversely, the current results suggest that the readers' performance was broadly similar when reading the fully and the selectively diacritized sentences, while it contained more errors even if it was quicker for undiacritized sentences. The reasons behind this discrepancy in results are not clear at this point.

Further, the results of Experiment 3 suggest that the more the meaning conveyed by the ambiguous word corresponded to a subordinate meaning, the more it profited from the addition of diacritics without it being slowed. What is more, diacritics improved accuracy of the subordinate meaning of the words, while they did not help in the comprehension of its dominant meaning. These results are in line with previous results from Experiment 1 and with those found by Hermena et al. (2016). One explanation for this phenomenon comes from Hermena et al. (2015) who suggested that the reader being used to seeing diacritics that disambiguate the least frequent meaning of the word, then his/her expectations for a subordinate diacritization when the word is diacritized leads to improved performance for this meaning. The results of this study provide partial support for this suggestion. Adding diacritics mostly improved access to the subordinate meaning of the heterophones. Yet, diacritics also improved the comprehension of single ambiguous words (in Experiment 1) for which the reader had no expectations. Thus, it is reasonable to conclude the reader's expectations definitely modulate the processing of diacritics as reported by Hermena et al. (2015), but additional factors such as reading strategie smight be at play when the ambiguity brought by heterophonic homographs has to be resolved.

Adding diacritics to only the ambiguous word in the sentence had similar or even better effects than adding diacritics to the whole sentence. Also, because only words with a subordinate meaning seemed to gain from the disambiguating benefits of diacritics, then it is logical to support the current practices in written Arabic in which only the ambiguous word with a subordinate meaning is diacritized in the sentence if needed. Of course, further studies are still needed to identify the conditions under which selective diacritization operates at best. Nevertheless, adding diacritics to the subordinate meaning of the heterophonic homograph is still inconsistently applied in everyday reading and confined to cases where the surrounding context does not provide significant cues to disambiguate the meaning of the word. The current results give support to the implementation of this practice more systematically for adult readers in order to help them better understand written material.

Finally, although adding diacritics could slow-down reading (even if marginally), it also made it significantly more accurate. Therefore, reading for comprehension being the main purpose of the act of reading, then some slowing during reading seems to be a fair price to pay for improved comprehension.

5 EXPERIMENTS 4-6 - HOW ARE THE MEANINGS OF AMBIGUOUS WORDS ACCESSED IN ARABIC?

5.1 Introduction

As a rule, heterophonic homographs are phonologically and semantically unambiguous when they are presented with diacritics as only one of their phonological interpretations is specified, but they can map onto two or more different pronunciations and meanings when they are presented without diacritics. In English, evidence suggests that both pronunciations and therefore meanings of heterophonic homographs are accessible to the reader even when they have a dominant meaning or when they are put in a context biasing the subordinate one (e.g., Folk and Morris, 1995). Also, the reader tends to read the heterophonic homograph aloud as the most dominant alternative even when biased towards the subordinate meaning (e.g., Folk and Morris, 1995; Gottlob et al., 1999). Therefore, although the context can bias the relative availability of the phonological code towards the subordinate meaning, it seems that its effects might be still too weak to completely override the initial strong association between the written word and its dominant meaning.

In contrast to English, in which the pronunciation of a heterophonic homograph can be disambiguated only by the constraints of a semantic context, Arabic can completely resolve phonological ambiguity by presenting a heterophonic homograph as a single word with diacritics without resorting to a context. When diacritics are added to a heterophonic homograph, only one of its phonological representations is specified, while the competing version is discarded. Thus, studying diacritized heterophonic homographs in Arabic is of particular interest because it might provide an additional demonstration of how semantic codes are modulated by the nature of orthographic-phonological and orthographic-semantic relationships. Because it allows the study of such words that have the same orthography but possibly different pronunciations, Arabic offers a unique way of investigating the contribution of orthographic and phonological processes in word recognition.

Experiment 1 examined the question of whether adding vowel diacritics to heterophonic homographs (thereby making them phonologically and semantically unambiguous) impacts their comprehension by the normal Arabic reader. Results reported in earlier chapters have suggested that the readers accessed the meaning of a heterophonic homograph in its diacritized form better than its undiacritized form which might correspond to two different meanings. Conversely, adding diacritics had no impact on semantic access to non-homographic phonologically unambiguous words. These findings clarified a major aspect of how diacritics impact on reading comprehension in Arabic. Still, further investigations are needed to shed additional light on the processes underlying access to the meaning of heterophonic homographsin both their ambiguous or their disambiguated form.

In this chapter, the primary concern is the way the meaning of a disambiguated diacritized word is accessed. For heterophones without diacritics, one possibility that is consistent with the *exhaustive access model* (e.g., Onifer and Swinney, 1981) supposes that all meanings of an ambiguous word are accessed simultaneously, and that context is used at a later stage to disambiguate the corresponding meaning. Another possibility in line with the findings for English readers in naming (e.g., Folk and Morris, 1995; Gottlob et al., 1999) is that only the dominant meaning of the heterophonic homograph is primarily accessed.

Alternatively, for heterophones with diacritics, it is possible that the word is completely disambiguated by diacritics, in the sense that it is processed like any other unambiguous word, whereby only its diacritized meaning is accessed. Otherwise, it is also possible that it is still processed like an ambiguous word even with diacritics. Obviously, if it can be shown that even when the word is presented disambiguated, the corresponding meaning to its alternative consonantal form is still activated, this will certainly provide significant evidence that both meanings of an Arabic ambiguous heterophone are always activated in reading. Otherwise, if only the meaning of the specific word is accessible without any interference from its corresponding homograph, then this finding would provide a confirmation that the heterophonic homograph is processed like any other phonologically unambiguous word. Besides, if it can be shown that the dominant meaning of an ambiguous word is activated, even when its pronunciation is clearly consistent with the subordinate meaning, then again this will clearly support the idea that the dominant meaning is predominantly retrieved when reading a single heterophonic homograph in Arabic. Comparisons between the strength of the relation between the reader's performance on one hand, and the familiarity vs. the dominance of the written word on the other hand can further clarify how dominance might impact reading. If the word's dominance affects performance, regardless of familiarity, then it can be concluded that the relative dominance effect may reflect the activation of the dominant meaning when the subordinate one is presented to the reader.

To address these matters, the present study aims to provide an additional investigation of the processes involved in semantic access of heterophonic homographs in their disambiguated (diacritized) form. Its specific objective is to determine whether both alternatives that share the same consonantal structure are activated at the same time even when one meaning is specified, or whether the diacritized word activates only its own meaning. For example, the consonantal undiacritized heterophone حداد */ħda:d/* is a balanced word that corresponds to two equally frequent pronunciations حِداد */ħida:d/ mourning* and حَدّاد */ħadda:d/ blacksmith* when diacritized. Usually, the reader encounters the undiacritized form حداد */ħda:d/* to access meaning in everyday reading. When s/he processes the diacritized alternative, then three scenarios are possible. One is that the reader accesses exclusively the meaning corresponding to حَدّاد */ħadda:d/ blacksmith*. Another is that the reader being used to reading the word in its undiacritized version, goes through a lengthier process by accessing both alternatives of حداد */ħda:d/* and then selecting حَدّاد */ħadda:d/* in opposition to حِداد

/ħida:d/. If حداد */ħda:d/* had a more or less frequent meaning among the two alternatives, then a third possibility is that the reader's habitual strategy being to read حداد */ħda:d/* as the dominant meaning, s/he would then take a shortcut and access the meaning directly. The context would later either discard or confirm this alternative.

The implication of this experiment for Arabic reading in general is a better understanding of the role of orthographic codes in word recognition. Recall that Frost and Bentin (1987, 1992) suggested that lexical access in Hebrew, a Semitic language similar to Arabic, is based on an abstract interface representation that is not phonologically detailed: the consonantal structure of the word without its superimposed diacritics. Note that since the proficient Arabic-readers typically reads undiacritized script in their daily life, they are more accustomed to reading words without diacritics and hence to seeing both versions of the heterophonic homograph as the consonantal entity defined by Frost and Bentin. If we are to draw a parallel with the English word *pint*, this orthographic entity would consist of a consonant (C) and vowel (V) CVCC segment, such as /pent/, in which the middle vowel is not clearly specified, ranging from /e/ to /I/ (Frost, 1998). Therefore, lexical decisions are supposedly generated before phonological disambiguation probably on the basis of the orthographic familiarity of this abstract orthographic representation of the word. Whether the effects of such a phonologically impoverished orthographic entity are still active post-access even when the word is phonologically disambiguated is one issue that this chapter aims to explore. Remember that orthographic information is more widely used in one Semitic language (i.e. Hebrew) than in other languages for both lexical decision and naming (e.g., Frost, Katz, & Bentin, 1987). Conjointly, an important claim of dual-route models (e.g., Coltheart et al., 2001) involves the dominance of visual-orthographic processing over phonological processing, at least for frequent words. Thus, it is expected that the orthographic codes play a major role in reading Arabic.

The following experiments aim to provide a fuller picture of the relative contribution of orthography to reading in Arabic by exploring the nature of the processing of heterophonic homographs when they are presented in their disambiguated form. It goes beyond lexical access, and seeks to clarify how the reader proceeds when s/he is provided with a diacritized heterophonic homograph and is asked to retrieve its meaning. To this end, performance on two types of words was compared. One type contained diacritized words that correspond to two semantically unrelated words (living/non-living) when undiacritized such as عالَم /ʕaːlam/ world and عالِم /ʕaːlim/ scientist. The other contained diacritized words that correspond to two words with related meanings (non-living/non-living) when undiacritized such as *شَعْر /ʃaʕr/ hair*, *شِعْر /ʃiʕr/ poetry*. Comparison of performance between the two types of words was considered as important because it could show the effects of the consonantal structure shared by the phonological alternative of the word (that is not needed for effective responding) on reading comprehension. If the effects of the competing word that corresponds to this abstract orthographic entity are present on target words, then performance on words with related meanings should be better than performance on words with unrelated meanings.

In the following investigations, the same set of stimuli was used across three experiments including two lexical access paradigms; the semantic categorization task and the lexical decision task. This allows us a cross-task comparison of the effect of the interfering meaning on semantic access. The critical findings are to be found in the semantic categorization task, a task requiring both identification and access to meaning. While semantic categorization requires a specific meaning to be activated to make a decision, lexical decision does not necessarily require the semantic code of the word in order to make a correct response (e.g., Balota & Chumbley, 1984; Bentin & Frost, 1987). Accurately responding to lexical decisions requires the recognition of the orthographic and/or at least the partial phonological form of the written string as a word.

The lexical decision task was used as a control task to determine whether the results in the semantic categorization task were due to experimental effects or to the choice of stimuli. That is, the compared words were matched for length, familiarity and dominance, but many other semantic or lexical dimensions such as imageability, number of semantic features, or neighborhood density that might have impacted performance were not controlled. Moreover, a naming task was used as another control task to better interpret performance in the categorical semantic task. Its aim was to investigate whether the participants recognized and read out the written word correctly, or whether they just read the more frequent form of the ambiguous words while disregarding the diacritics. Although evidence from Experiment 1 suggests that readers of Arabic do not ignore diacritics when these are superimposed on the word, and that they make use of any additional phonological information even though it can be redundant, it is still possible that the reader being more familiar with the undiacritized script, s/he would ignore the added vowels (e.g., see Hermena et al., 2015) and process the most frequent meaning of the word. If this was the case, then the interpretation of the readers' performance on the semantic categorization task would be more challenging.

5.2 Experiment 4

5.2.1 Aims

Experiment 4 was designed to explore semantic access to ambiguous words through a semantic categorization task whereby the participant is asked to determine if a presented word could have a living meaning. Words were presented in a diacritized form and, in the critical condition, the task was to decide if a word that had both a living and a non-living meaning when presented without diacritics had a living meaning (the diacritics were consistent with the non-living meaning of the word). Would performance be slower or less accurate than for ambiguous words where both of the meanings were non-living? That is, would the living meaning interfere with accessing the non-living meaning of the diacritized word? The objective of the experiment was therefore to determine whether a diacritized homophone that corresponds to two semantically unrelated words (living/non-living) when undiacritized is processed as quickly and as accurately as a diacritized word that corresponds to two words with related meanings (non-living/non-living) when undiacritized.

5.2.2 Method

5.2.2.1 Participants

The sample of the size in the three next experiments was determined in reference to Experiment 1. The participants were 30 undergraduate students, all Arabic native speakers, who were volunteers. All were females. They all had a Lebanese high school degree (Baccalaureate), and could therefore be considered as proficient in Arabic reading, as Arabic language is widely covered in the Lebanese baccalaureate curriculum. Like the majority of Lebanese university students, they had all pursued their studies in a second language (English or French). They had not completed any university degree, and were enrolled in a school of public health at the Lebanese University. Their ages ranged between 18 and 25 years. None of the participants had school difficulties or suffered from neurological, emotional, attentional, or learning disorders. Their vision was normal or corrected to normal. All participants signed a consent form approved by the University of Essex prior to performing the experimental tasks. Ethical approval was granted by the University of Essex Science and Health Faculty Ethics committee.

5.2.2.2 Materials

Two 21-word-lists were created. All words were nouns preceded by the copula ‘al’ equivalent to the English copula ‘the’ to prevent confusions with other word types such as verbs or adjectives; they contained three to six letters.

The first word list was chosen from a previously designed set of heterophonic homographs having one living and one non-living meaning corresponding to two different pronunciations (cf. Experiment 1). Each word was previously graded for subjective familiarity and for dominance of meaning by 10 independent raters. All the words were diacritized and the non-living form of the ambiguous word was presented.

A second equivalent list of words was created for the purpose of this experiment. A preliminary set of 37 ambiguous words having two non-living meanings was formed. Two pilot experiments were conducted to estimate the subjective familiarity and the meaning dominance of this initial pool of words. 10 participants having the same characteristics as the main experiment’s participants were asked to rate from 1 to 5 the familiarity of the two diacritized versions of the word. 10 other similar participants were asked to define the undiacritized form of the words two times. Their results were rated as the first and the second availability of the word, and were considered as an indicator of the relative dominance of each meaning of the word. The words from each list were matched for length, familiarity, and dominance; 21 words were kept for the final set. The first availability of the living meaning of the ambiguous word was used as a measure of dominance. Independent t-tests were carried out on the first and second list, and there was no difference in the level of familiarity, $t(40) = 1.34$, $p \leq .05$; length, $t(40) = 1.21$, $p \leq .05$; or dominance, $t(40) = .14$, $p \leq .05$ between the two lists. In general, words with one non-living meaning and one living meaning had similar familiarity (*M* = 4.51, *SD* = 0.47) to words having two non-living meanings (*M* = 4.69, SD = 0.34), as well as similar length (*M* = 3.81, *SD* = 0.68; *M* = 3.57, *SD* = 0 .60), and dominance (*M* = 5.62, *SD* = 3.40; *M* = 5.48, *SD* = 3.34).

Samples of the words are given in table 5.1.

Diacritized version of an ambiguous word with two non-living meanings	**Diacritized non-living version of an ambiguous word with one living and one non-living meaning**
السُحَاب	الخَلْف
المَرْكَب	السَّلْق
البِرْكَة	النُّور
السُكْر	الجِدَاد

Table 5.1: Examples of words used in Experiment 4, 5, and 6.

All words were diacritized. 42 diacritized unambiguous words having one living meaning were used as fillers.

5.2.2.3 Apparatus and Procedure

Superlab software was used to present the words in a random order. Words were presented in Arial size-66 font on a white screen using an HP Pavilion g6 laptop. All stimuli were fully diacritized except for their ending. The diacritization was similar to that found in a widely used dictionary. Response latencies were measured to the nearest millisecond. The participants were tested individually. They sat about 50 cm from the monitor and used both their hands to answer. At the beginning of each trial, a fixation cross was presented in the center of the screen for 2 seconds. Then the first word appeared in the center of the screen. The word remained on the screen until the participant pressed one of two keys on the computer keyboard. Participants were tested individually. They were instructed to look at a cross in the middle of the screen between stimuli, and to press a yes (F) key if the word they see represents a non-living thing, or to press a no key (J) if it cannot represent a living thing.

5.2.3 Results and Discussion

Mean semantic categorization decision latencies for correct responses and mean correct answers were calculated across subjects and across items. Significant effects reported in all experiments were based on a .05 alpha level. Accuracy was a measure of word comprehension; it revealed how well a single written word was understood. Reaction times (RTs) to recognized words, measured the speed of word comprehension.

Across participants, a paired-samples t-test was conducted to compare the number of recognized words between unrelated diacritized ambiguous words having one of their versions with a non-living meaning and the other one with a living meaning and related diacritized ambiguous words having both their versions with a non-living meaning. Another paired-sample t-test was conducted to compare RTs to correctly recognized words in the similar and the different competing meanings conditions.

There was a main interfering effect of the competing meaning of the ambiguous word on the accuracy scores, $t(29) = 6.61$, $p < .0001$, $d = 0.92$ and on reaction times, $t(29) = 4.73$, $p < .0001$, $d = 0.41$). On average, participants had significantly better accuracy scores when they were shown a diacritized word having two non-living versions/meanings if undiacritized ($M = 17.6$, $SD = 2.79$) than when they were shown a diacritized word having one living and one non-living version/meaning if undiacritized ($M = 14.7$, $SD = 3.4$). Reading speed was also significantly slower when the word had one non-living and one living meaning (M = 2215, SD = 800), than when it had two non-living meanings (M = 1920, SD = 627).

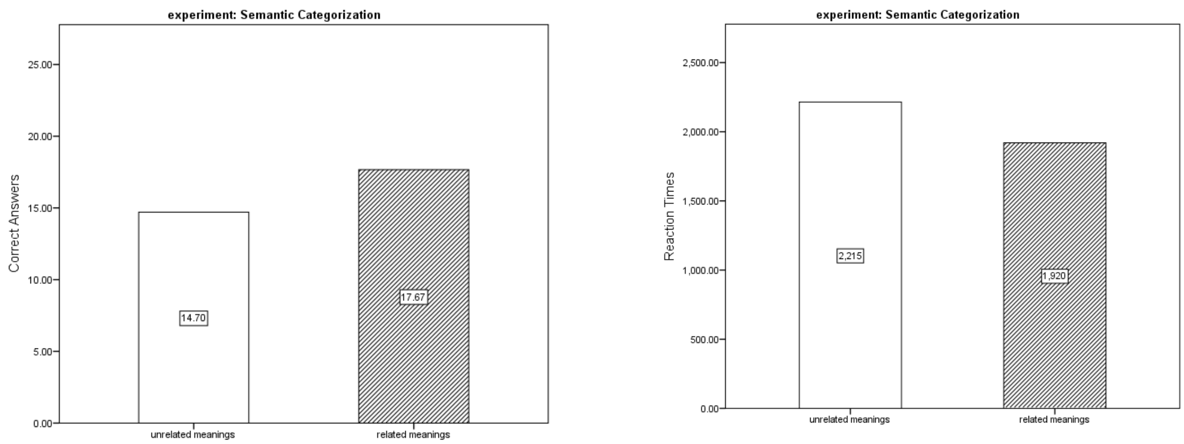

Figure 5.1: Comparison of accuracy and latency scores between words with related and words with unrelated meanings in Experiment 4.

The most important finding of Experiment 4 is that the competing (unrelated living) meaning of a diacritized homograph (with a non-living meaning) significantly interferes with the retrieval of its semantic representation, making performance significantly less accurate and significantly slower. These results suggest that the addition of vowel diacritics to disambiguate heterophones does not lead the reader directly to the appropriate meaning in memory, but that on the contrary, even when the heterophone is presented as a completely unambiguous word, the reader still has to decide among several meanings that are associated with the consonantal structure of this disambiguated heterophone before responding.

In addition, correlations between words' characteristics and performance on this semantic categorization task did not reach significance, which indicates that the relationship between how quickly a word was recognized and how familiar (*unrelated meanings*: r = -. 17, p = .43; *related meaning:* r = -.03, p = .95) or dominant (*unrelated meanings*: r = -.30, p = .17; *related meaning:* r = -

.40, p = .06) it is, was present, but not statistically significant. Reading accuracy was also not statistically correlated with dominance (*unrelated meanings*: r = -39, p = .07; *related meaning: r* = .04, p = .84), nor with familiarity (*unrelated meanings*: r = .30, p = .17; *related meaning: r* = -.30, p = .17). Of note, words that are dominant tend to also be familiar and vice versa (r = -.67, $p \leq .0001$).

Further discussion of the theoretical implications of Experiment 4 will be postponed until results of Experiment 5 and 6 are explained.

5.3 Experiment 5

5.3.1 Aims

Experiment 5 used the same stimuli as Experiment 4, but in a lexical decision task. It was conducted as a control experiment to examine whether the results of Experiment 4 were related to semantic retrieval or to other factors relating to possible uncontrolled differences between the experimental words and the control words such as their frequency, imageability etc.

5.3.2 Method

5.3.2.1 Participants

The participants were 30 undergraduate students drawn from the same population as Experiment 4. None of them had participated in Experiment 4. 28 were males and 2 were females. All participants signed a consent form approved by the University of Essex prior to performing the experimental tasks. Ethical approval was granted by the University of Essex Science and Health Faculty Ethics committee.

5.3.2.2 Materials

The experimental stimuli were the same as experiment 4. They were formed of two lists of 21 diacritized words. Both lists were composed of diacritized words with a non-living meaning. In the first list, the words could correspond to a non-living meaning when undiacritized, while in the second list, the words could correspond to a living meaning when undiacritized. The fillers were non-words that were created by changing the first letters of the fillers with a living meaning used for experiment 4.

5.3.2.3 Apparatus and Procedure

Superlab software was used to present the strings in a random order. Letter strings were presented in Arial size-66 font on a white screen using an HP Pavilion g6 laptop. All stimuli were fully diacritized except for their ending. The diacritization was similar to that found in a widely used dictionary. Response latencies were measured to the nearest millisecond. The participants were tested individually. They sat about 50 cm from the monitor and used both their hands to answer. At the beginning of each trial, a fixation cross was presented in the center of the screen for 2 seconds. Then the first word appeared in the center of the screen. The word remained on the screen until the participant pressed one of two keys on the computer keyboard, a yes (F) key if the stimulus was a word, or a no (J) key if it was not a word.

5.3.3 Results and Discussion

Mean lexical decision latencies for correct responses and mean accurate responses were calculated across subjects and across items. T-tests were conducted to compare the accuracy and the speed of reading between diacritized ambiguous words having both their versions with a non-living meaning and diacritized ambiguous words having one of their versions with a non-living meaning and the other one with a living meaning.

Results of the paired-samples t-tests showed that there was no longer any interfering effect of the meaning of the competing version of the ambiguous word on accuracy scores, $t(40) = .49$, $p = .52$, $d = 0.19$), nor on reaction times, $t(29) = 1.50$, $p = .14$, $d = 0.19$. The number of correct responses to lexical decisions for words having an unrelated (living) competing version ($M = 16.7$, $SD = 4.6$) did not differ from that for words having a similar (non-living) competing meaning ($M = 17.3$, $SD = 5.2$). On average, time to decide on lexicality did not differ between words having a different (i.e., living) competing meaning (*M* = 1780, *SD* = 839) and those having a similar (i.e., non-living) meaning (*M* = 1636, *SD* = 656).

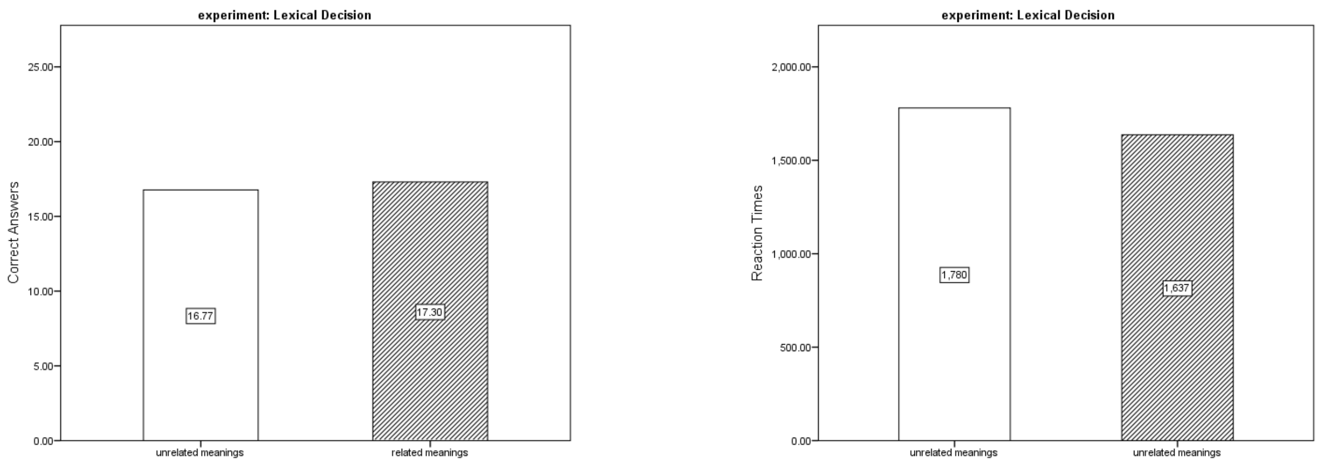

Figure 5.2: Comparison of accuracy and latency scores between words with related and words with unrelated meanings in Experiment 5.

Additionally, correlations between words characteristic and performance in lexical decision indicated that unlike results in semantic categorization, there was a statistically significant relationship between how accurately a word was recognized as such and its familiarity (*unrelated meanings*: r = .59.,p = .004; *related meaning:* r = .72,$p \leq$ .0001) and dominance (*unrelated meanings*: r = .61, p = .003 ; *related meaning:* r = .63, p = .002). Speed of lexical decision was negatively correlated with dominance and familiarity for the heterophone having another unrelated meaning (*familiarity*: r = -.62, p = .002; *dominance*: r = -*.68*, p = .001), but they did not correlate for homophones with related meanings (*familiarity*: r = -.08, p = .71; *dominance*: r = -*.13*, p = ..57).

Overall, the results of this experiment indicate that the meaning congruence advantage observed in the semantic categorization task (Experiment 4) was not observed in lexical decision. There was no difference in accuracy and RTs in lexical access on a lexical decision task between the two sets of words. Latencies and error rates were similar between words having two semantically related versions and those having two semantically unrelated versions.

Also, correlations suggest that the more familiar the word is and the more dominant its meaning is, the better it is recognized as word. Lexical decision appears also quicker for the more dominant meaning in one of the word sets but not for the more familiar word.

5.4 Experiment 6

5.4.1 Aims

Experiment 6 used the same stimuli as Experiment 4 and 5, but using a naming task this time. It was conducted to further understand whether or not the congruency advantage observed in Experiment 4 might have occurred because the participants ignored the diacritics of the word while reading it and thereby, they recognized the more dominant meaning of its corresponding undiacritized string.

5.4.2 Method

5.4.2.1 Participants

The participants were 30 undergraduate students drawn from the same population as Experiment 4. One of them was a male and the others were females. None of them had participated in Experiment 4 or 5. All participants signed a consent form approved by the University of Essex prior to performing the experimental tasks.

5.4.2.2 Materials

The experimental stimuli were the same as experiment 4. They were formed of two lists of 21 diacritized words with a non-living meaning. In the first list, the words could still correspond to a non-living meaning when undiacritized, while in the second list, the words could correspond to a living meaning when undiacritized.

5.4.2.3 Apparatus and Procedure

Inquisit software was used to present the words in a random order and record the participants' responses. Words were presented in Arial size-66 font on an on an HP Pavilion g6 laptop. Participants were tested individually. They sat at 50 cm of the monitor. They were instructed to look at a cross in the middle of the screen between stimuli, and to read the presented words aloud as quickly and as accurately as possible. Naming latency was measured from the onset of the word stimulus to the onset of the vocal response.

5.4.3 Results and Discussion

Mean reading latencies for correct responses and mean correct answers were calculated. Paired samples t-tests were performed to determine if there was a difference between reading aloud non-living words having an unrelated living meaning, and reading aloud non living words that have a similar non-living meaning. There was no significant difference in the accuracy scores of words with two non-living meanings (M = 20.2, SD = 0.81) and those with one living and one non-living meaning meanings (M = 20.4, SD = 0.71), $t(24)$ = 1.29, p = .20, d = 0.31). Likewise, there was no difference between the reaction times to the two types of words (similar meanings: M = 880, SD = 124; Unrelated meanings: (M = 860, SD = 106), $t(24)$ = 1.76, p = .09, d = 0.17).

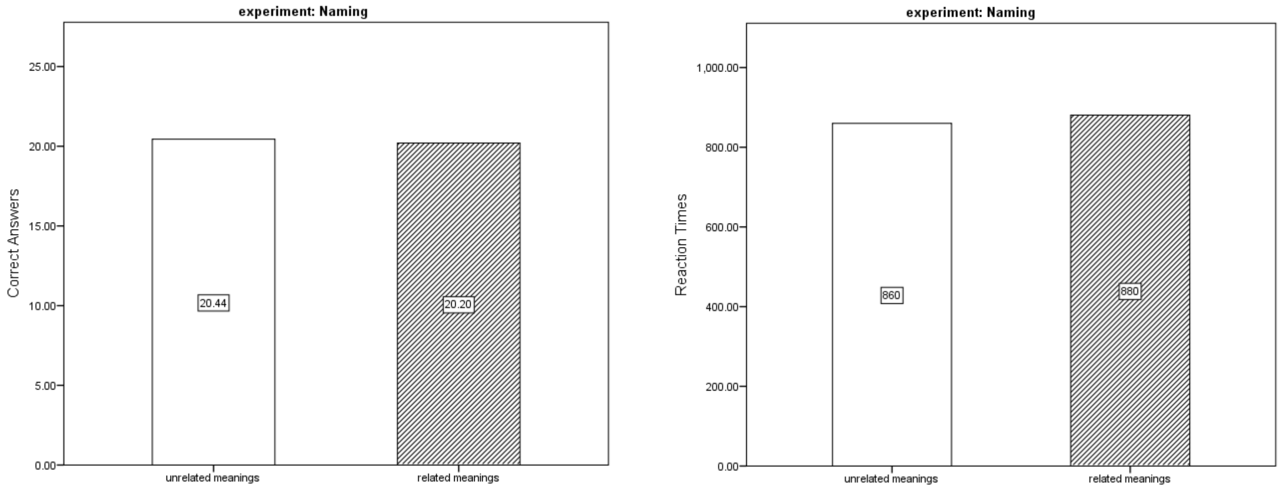

Figure 5.3: Comparison of accuracy and latency scores between words with related and words with unrelated meanings in Experiment 6.

Results on correlations between word characteristic and performance in naming did not reveal any statistically significant relationship between performance (accuracy and speed) and familiarity of dominance for both related and unrelated meanings. Correlations between dominance and reaction times approached significance.

Results are summarized in table 5.2.

	Diacritized non-living version of a homophone having an unrelated living version		Diacritized non-living version of a homophone having a related non-living version	
	Reaction time	Accuracy	Reaction time	Accuracy
Familiarity	*r = -.29*	*r = .22*	*r = .05*	*r = -04*
	p = .19	*p = .32*	*p = .81*	*p = .83*
Dominance	*r = -.39*	*r = .26*	*r = -.34*	*r = .19*
	p = .07	*p = .25*	*p = .13*	*p = .38*

Table 5.2: Correlations between word familiarity and dominance and naming performance in Experiment 6.

Combined, the results of Experiment 6 indicate that there is no difference in accuracy scores and RTs between naming words corresponding to two semantically related congruent versions when undiacritized and naming words corresponding to two semantically unrelated incongruent versions when undiacritized. Accuracy scores were also typically near ceiling, indicating that the word's phonology was almost always accurately retrieved by the reader who pronounced the diacritized heterphones correctly most of the time.

Moreover, the correlation results suggest that words are generally read aloud without many errors, whether they are more or less familiar or when their meaning is more or less dominant. Reading aloud is also marginally quicker when the meaning is more dominant but not when the word is more familiar, suggesting the reader might have initially activated the most frequent alternative of two but s/he had then to review his/her initial response similarly to data reported for English results (Carpenter & Daneman, 1981; Folk & Morris, 1995).

5.5 Across-Experiments Comparisons

	Experiment 4 Semantic Categorization		Experiment 5 Lexical Decision		Experiment 6 Naming	
	Ambiguous words with one living and one non-living meaning	Ambiguous words with two non-living meanings	Ambiguous words with one living and one non-living meaning	Ambiguous words with two non-living meanings	Ambiguous words with one living and one non-living meaning	Ambiguous words with two non-living meanings
Accuracy	M = 14.70 SD = 2.79	M = 17.66 SD = 3.46	M = 16.76 SD = 4.65	M = 17.30 SD = 5.22	M = 20.44 SD = 0.71	M = 20.20 SD = 0.81
ReactionTimes	M = 2215 SD = 800	M = 1920 SD = 627	M = 1780 SD = 829	M = 1636 SD = 656	M = 860.06 SD = 106.23	M = 880.47 SD = 124.95

Table 5.3: Mean and standard deviations of accuracy and latency scores in Experiments 4, 5, and 6.

The number of accurate responses and the latency times to correct responses were subjected to a two-way mixed analysis of variance. The performed task (semantic categorization, lexical decision, naming) was a between-subjects variable, and the relatedness/congruence of meanings (related, unrelated) was a within-subjects variable. The reason for conducting this analysis was to look for an interaction between relatedness of meaning and experimental task. A significant interaction would support the conclusion that the effects of relatedness differed as a function of the nature of the experimental task.

The main effect of relatedness of meaning yielded an F ratio of $F(1, 82) = 30.8$, $p < .001$ for accuracy scores and an F ratio of $F(1, 82) = 11.9$, $p = .001$ for reaction times indicating that the participants had different scores (accuracy and reaction times) when they were responding to words having a competing related meaning (non-living), from when they were responding to words having a competing unrelated meaning (living). Overall, participants responded to words with related meanings more accurately ($M = 18.2$, $SD = 3.9$) and more quickly ($M = 1514$, $SD = 879$) than to words with discrepant meanings (Accuracy: $M = 17.1$, $SD = 3.9$; Reactions Times: $M = 1663$, $SD = 879$). The interaction between the task and relatedness of meaning was significant for both accuracy, $F(2, 82) = 24.5$, $p \leq .001$ and reaction times, $F(2, 82) = 4.9$, $p = .009$, indicating that the effect of the relatedness of meaning was different across tasks. To further understand this interaction, the reader is refered to the t-tests performed on the accuracy and reaction time scores of words with related vs. unrelated meanings (see Experiments 4, 5, and 6 above).

Taken together, the data from the three reported experiments in this study provide strong evidence that the advantage of meaning congruence in semantic categorization is indeed a real one; the relatedness of meaning between the two (phonological and therefore semantic) alternatives that share the same orthography had a significant effect on semantic categorization but not on any other task. This is because when the readers responded “no” to a task whereby they are asked if a word with diacritics has a living meaning, their performance was better when the consonantal structure of the word (without diacritics) had another non-living meaning, than when it had an alternative living meaning. The readers' performance was conversely similar between the two types of words both when they read the word aloud (Experiment 6) and when they recognized it as a real word (Experiment 5).

5.6 Discussion of Experiments 4-6.

The purpose of the present study was to provide a fuller picture of the way readers understand heterophonic homographs when they are presented in their disambiguated diacritized form in the absence of a context. By doing so, the aim was to expand our understanding of how phonologically ambiguous words are accessed in Arabic. The findings extend to contribution of orthography vs. phonology in reading Arabic and it sheds a new light on the strategies used by Arabic readers for reading comprehension. The key interest was to determine whether a phonologically and semantically unambiguous word (i.e. heterophonic homograph with diacritics) that is possibly ambiguous if presented in another form (i.e. heterophonic homograph without diacritics) is processed like any other unambiguous word (i.e. random word with diacritics) or not. The logic was that if a diacritized heterophonic homograph is processed like any other unambiguous word, then sharing an orthographic representation with another word will not affect its processing. Conversely, if it is not accessed like other diacritized words, then its processing will likely be affected by the orthographic representation this word shares with its homograph (i.e., the consonantal structure of the heterophonic homograph without diacritics).

An unexpected but striking pattern of results has emerged from the research conducted in this thesis: the reading times that we observed for words in Arabic were much longer than reading timesthat have been observed in other languages. This pattern remained consistent across lexical decision, naming, and semantic categorization. For instance, mean RTs for correct semantic categorization were 2067ms. in Experiment 4, while RTs in a corresponding semantic judgment task using English heterophones averaged only 760ms. (Gottlob et al., 1999). Similarly, in comparison to English and even Hebrew, Arabic naming and lexical decision were significantly more time consuming. Compare for example the present results (Naming: 870ms.; Lexical Decision: 1708) to those reported for heterophones in English (Naming: 493ms.; Lexical Decision: 670ms.) (Gottlob et al., 1999; Folk and Morris, 1995) and Hebrew (Naming: between 650ms. and 800ms.; Lexical Decision: between 600ms. and 1000ms.) (Bentin and Frost, 1987).

These findings are in line with some earlier research suggesting thatprocessing words in Arabic is slower than in other languages (e.g., Roman and Pavard, 1987). The slow RT smight be explained by several interacting factors. One factor could be the complexity of the Arabic script, being characterized by its cursive writing and its similar letter forms. In one experiment, Ibrahim and Eviatar (2002) compared readers' performance on an oral vs. a written Trail Making Test. Their results suggested that the recognition of Arabic letters is significantly slower than that of both Hebrew and Latin letters, due to the orthographic visual complexity of Arabic letters. In addition, the effects of diglossia (reading a language that is not spoken by the reader) may be an another factor that impacts the speed of word recognition in Arabic. Diglossia is known to delay reading acquisition by creating a linguistic distance between the oral mother tongue and the unspoken written language (Saiegh-Haddad, 2003, 2004). Although its effects have not been directly studied in proficient adult Arabic readers, it is likely that diglossia contributes to the observed slowing in reading Arabic words, because of the many morphological, phonological, and lexical differences it creates between the written letter strings and their corresponding everyday spoken words.An additional factor delaying the processing of Arabic written words might be their complex morphology (for more details, see paragraph 2.2.2). Arabic words are morphologically denser than European ones. Given the intricate morphemes included in a single written Arabic string, it is expected that the mental decompositionof such morphemes demands more cognitive capacity, and therefore requires more time to be completed. Finally, it is possible that because readers of Arabic have to rely on context significantly more than readers of other languages (Abu-Rabia, 1997, 2001), they find reading single words as an unusual and strange act, and require a significant amount of time in to comple it. Of course, other explanations are possible, and the previous explanations are still speculative at this stage. The implication of the specificities of Arabic might partly explain the delayed word processing times found in Experiments 4, 5, and 6, but more research is still needed to substantiate these hypotheses.

Importantly, the results of the three experiments reported here indicated that responses in a semantic categorization task whereby the reader is asked whether a written heterophone with diacritics can have a living meaning were delayed and more error-prone when the consonantal structure of the word (i.e., the word without diacritics that the reader encounters in daily reading) corresponded to one living and one non-living meaning in comparison to a word that corresponded to two non-living meanings. This was taken as evidence that even when a heterophone was disambiguated by diacritics, one of its phonological alternatives still influenced access to its other alternative. As a result, when a task required the meaning to be determined, then the competition between the two meanings that share the same orthography needed to be resolved before responding. In opposition, no such meaning congruency advantage was found for lexical decision or naming.

Taken together, the three experiments suggest that even when a certain homophone is phonologically disambiguated, its semantic processing is still influenced by the alternative pronunciation and meaning that shares its consonantal structure. One explanation of this effect is that the phonologically underspecified consonantal structure of a word in Arabic automatically activates all the different meanings and pronunciations to which it might refer, even when it becomes fully specified by diacritization. Previous data from Hebrew (a Semitic language similar to Arabic) has already demonstrated that all alternative phonological and semantic words are automatically activated by the unique orthographic pattern they share (Frost and Bentin, 1992) and that orthographic information is used for lexical decisions and naming more extensively in Hebrew than in other languages (Frost, Katz, & Bentin, 1987). Experiments 4-6 proceed further by demonstrating that both alternatives of a consonantal heterophone are still active not only in lexical decision and naming, but also after a semantic decision has been made in semantic categorization. More importantly, the automatic activation of both meanings related to a consonantal structure still occurs, even when one of them is clearly defined by the addition of disambiguating vowels. These findings may be interpreted as supporting a model in which the abstract orthographic entity formed by the consonantal structure of a word as defined by Frost and his colleagues (e.g., Bentin and Frost, 1987; Frost 1992, 1998, 2012) appears to remain active in word recognition well beyond lexical access and well into semantic selection.

Combined, these results provide additional evidence that readers of Arabic still use the lexical route when reading the shallow version of their orthography (at least for semantic access). In fact, it is mostly accepted that in deep orthographies, readers prefer to use the addressed routine to derive phonology, notably in naming. Obviously this is because readers simply cannot assemble phonology from the opaque orthographic structure of the word through grapheme-to-phoneme correspondence. Moreover, the fact that Hebrew readers access the lexicon through a lexical route by recognizing the word's orthographic structure is well established (e.g., Frost and Bentin, 1992b). What is more, supporters of the orthographic depth hypothesis (Katz & Feldman, 1981; Feldman & Turvey 1983; Frost, Katz & Bentin, 1987; Katz & Frost, 1992) claim that readers of a deep orthography such as that of undiacritized Arabic use the visual-orthographic codes to recognize words, while in the shallower diacritized Arabic, phonological information being more complete, a phonological process of decoding which seems to be faster (at least for low-frequency words) occurs (Navon and Shimron 1981; Shimron and Navon 1982; Bentin et al., 1984; Koriat 1984, 1985; Bentin and Frost 1987; Frost, 1994; Frost et al., 1987; Frost and Bentin, 1992b). In contrast, the results reported above suggest, that even when reading the shallow diacritized Arabic, the reader who is trained to use mainly the lexical route cannot ignore the orthographic structure of the word, and therefore is still influenced by the alternative phonological representation of the word s/he certainly recognized.

In the context of the previous experiment, the participants were faced with an unusual condition whereby they read isolated words without context but with added unfamiliar diacritics. Results from Experiment 1 combined with reported evidence from Hebrew (Navon & Shimron, 1981, 1984) suggest that readers do not ignore diacritics when these are added to the script. Therefore, if reading diacritized Arabic is based only on an assembled phonology then the reader should not be affected by any alternative pronunciation of the consonantal string. However, this was not the case. It appears that the readers being used to typically match the undiacritized heterophonic homograph to two phonological and semantic alternatives, they continued to do so, even when one alternative was clearly specified. Even if adding diacritics completely clarified the word phonologically and semantically, it could not prevent the initial and more typical association of its orthography with two different pronunciations and meanings.

Finally, results of earlier studies in Hebrew (e.g., Bentin & Frost, 1987) have indicated that, in the absence of biasing context, the order of activation of heterophonic homographs is determined by their relative frequency, with dominant meanings being accessed before subordinate ones. Results of the previous experiments did not provide additional information on which model of accessing ambiguous words best represents the way heterophonic homographs are disambiguated in Arabic. No definite association was found between the dominance of the word's meaning when it was presented with diacritics and how quickly or accurately it was read.

6 GENERAL DISCUSSION

6.1 Introduction

Most reading research has concentrated primarily on the English orthography, partly because researchers have made the assumption that reading (like other cognitive processes) is universal, and that findings from one orthography can be easily generalized to others. However, this widely held belief has been repeatedly challenged (e.g., Frost, 2012; Share, 2008; Ziegler & Goswami, 2005), thereby inspiring the expansion of new cross-linguistic studies of reading in a variety of languages around the world.

Arabic is one of these important languages that can provide an interesting point of reference in cross-linguistic reading research, especially given that it is a primarily consonantal system in which the majority of vowels are superimposed above and below the word as diacritical markers. The routinely used undiacritized Arabic that is the typical presentation used in everyday reading, specifies most consonants but few vowels. Undiacritized Arabic is considered as a deep orthography in which the relation between graphemes and phonemes is equivocal. Conversely, diacritized Arabic, that is used for learning to read Arabic and in particular situations in which phonology is primordial (e.g., poetry and liturgical texts), represents all phonemes by mainly using consonants as letters and vowel as diacritics above and below the letters. Diacritized Arabic is considered as perfectly shallow in the way that letters consistently represent the sounds of the language. When diacritics are omitted, heterophonic homographs are commonplace; these are words like *tear* in English in which a single spelling maps onto at least two pronunciations. Undiacritized heterophones have two or more phonological (and therefore semantic) representations, while diacritized heterephones are unambiguous and entirely transparent in terms of orthography-to-phonology correspondence.

The key interest of this thesis is the way readers of Arabic mentally process the two extremes in 'phonological depth' represented by written Arabic with and without diacritics. For Arabic users, reading with few if any vowel signs is generally simple and effortless; recognizing an undiacritized deep script with few specified vowels is their normal way of reading. In addition, they can rely on the shallower diacritized Arabic that completely clarifies pronunciation, and in which they can be also efficient. Because readers are proficient in both forms of script, they can be tested in both situations while still providing maximum control for the individual differences. Thus, examination of the contribution of diacritics to reading Arabic is of special interest, along with the way heterophonic homographs are processed. Also, because comprehension is essential to reading, the tasks performed by the adult skilled participants in this thesis are essentially semantic ones whereby the readers are required to understand what they read in order to respond correctly.

6.2 Summary of Empirical Findings

Experiment 1 attempted to learn more about how the use of diacritics impacts on semantic processing of single Arabic words. Its aim was to determine whether adding phonological and visual information by presenting words with diacritics benefits or hinders single word reading comprehension, and whether the effects of diacritics differ depending on the characteristics of the words they are added to (i.e., ambiguous vs. unambiguous, more or less familiar, more or less dominant). The task required participants to decide whether a word had a living meaning or not; the presented words were either phonologically unambiguous words that had only one pronunciation when undiacritized, or ambiguous heterophonic homographs that had two different pronunciations and meanings when undiacritized. The words were presented with and without diacritics. The results indicated that diacritics had different effects on words depending on their ambiguity: while diacritics improved access to meaning of heterophonic homographs, they did not influence their reading times. Conversely, while diacritics did not alter accuracy scores of unambiguous words, they slowed them down. Moreover, correlations suggested that the addition of diacritics appeared to improve the comprehension of ambiguous words mostly when it clarified the least dominant meaning of the word.

In Experiment 2, the words were embedded in a sentence in the interest of generalizing the results from Experiment 1 to an activity that resembles normal reading more than a single-word task. The participants were asked if a sentence that contained the words from Experiment 1 was meaningful. The sentences were presented with and without diacritics, and they contained the phonologically ambiguous and unambiguous words used in Experiment 1. The addition of diacritics was found to delay reading in all sentences, and to improve comprehension only for sentences containing a heterophonic homograph. When results of Experiment 2 were compared to those of Experiment 1, it appeared that putting a word in a sentence improved its understanding both when it was diacritized and undiacritized. Also, adding diacritics to sentences (containing a heterophone) still improved their comprehension, but a comparison of the results of Experiment 1 and 2 showed that the effect of diacritics was significantly smaller on sentences than on words.

Experiment 3 was designed following the findings from Experiment 1 and 2 which led to the conclusion that diacritics facilitate the comprehension of heterophonic homographs (by making responses more accurate and not affecting speed) while they hinder the comprehension of non-heterophones (by slowing them without affecting the accuracy of their responses). As a result, it seemed reasonable to investigate whether there was an optimal reading condition in which diacritics are added to only those words that benefit from them. This is because a positive trade-off between reading speed and reading accuracy might be maximized in such a case. Reading would become more accurate with the adding of the disambiguating diacritics to the heterophonic homographs, without the rest of the sentence being slowed. Thus, in Experiment 3, the participants' performance was compared on sentences that were presented either undiacritized, with selective diacritization of the heterophonic homograph, or with full diacritization of the whole sentence. Findings from Experiment 3 showed that the addition of diacritics (whether on one word or on the whole sentence) improved the comprehension of sentences. Combined, the results did not clearly indicate that the selective diacritization condition was the most economic way to use diacritics (by improving comprehension without affecting reading speed); the difference in accuracy and speed between reading sentences in which only one word was diacritized, and sentences that were fully diacritized was not found to be significant. Importantly, the addition of diacritics appeared to mainly benefit access to the subordinate meaning of the word.

The last three experiments were conducted to provide further data on whether one or both meanings of a heterophone are activated when reading diacritized Arabic. To this end, semantic decisions on two sets of diacritized heterophonic homographs were compared. One set contained heterophonic homographs (presented in their non-living meaning) that have two unrelated (non-living/living) alternatives when undiacritized. The second set of words contained heterophonic homographs (presented in their non-living meaning) that have two related (non-living/non-living) alternatives. One example of the experimental words of Experiments 4, 5, and 6 is the word سِباحَة */siba:ħat/ swimming* that might be read as سَبّاحَة */sabba:ħat/ swimmer* with a different pattern of diacritics. The same stimuli were used across three tasks: semantic categorization (Experiment 4), lexical decision (Experiment 5), and naming (Experiment 6). The key issue was whether the alternative meaning of a diacrtized heterophone would have any effect on performance. If so, performance in semantic decision would be slower and maybe more error-prone for words with unrelated meanings. The main analysis was carried out on the semantic decision task, while the two other experiments were used primarily as control conditions in order to modulate the effects of the experimental words' lexical factors, and therefore to analyze the results of the main experiment with more precision. The results indicated that words with two unrelated meanings were processed more slowly and less accurately than words with two related meanings, suggesting that even when diacritics were added to a heterophone, it was still processed to some extent as if it were ambiguous and both of its meanings were activated. This result was taken as evidence that diacritizing a word and completely clarifying it phonologically could not override the initial association between its undiacrized orthography and its two different meanings. In addition, no evidence was found that the dominant meaning was preferentially accessed; correlation results from Experiments 4, 5, and 6 suggested that both meanings related to an undiacritized homograph are accessed in reading, regardless of dominance. It appears that even when the meaning corresponding to a heterophonic homograph is the dominant one (e.g., مَنْجَم */mandʒam/ mine)* the other alternative corresponding to its consonantal structure (e.g., مُنَجِّم */munadʒdʒim/ magician*) is also activated even when the word is presented in its diacritized form.

6.3 Theoretical Implications

Combined, the findings that emerged from the six experiments conducted in this thesis shed a new light on aspects of the cognitive processes involved in reading Arabic. The results from these experiments together with findings from the literature can provide additional insight to some prominent questions pertaining to the psychology of reading Arabic.

How do diacritics contribute to reading in Arabic?

A central question in the Semitic reading literature is whether diacritics are automatically processed in reading. Researchers have tried to address this issue by determining whether readers can focus on only the orthographic form of a word (the written word) while ignoring its phonological recoding (the word and its diacritics). It appears that even when readers are instructed to disregard diacritics, they process them automatically in the condition of single word reading. As a result, phonemic interference induced by incorrect diacritization is unavoidable (Navon and Shimron, 1981; Shimron and Navon, 1982). Within a context, in normal text reading, vowels might be however disregarded by the reader when they are added to sentences (Hermena et al., 2015). Hermena claims that readers do not process the disambiguating vowels that would indicate a subordinate meaning of a word when all the words in a sentence are diacritized. Instead, they read it as the potentially most prevalent one. The results reported in this study provided some support for both divergent views; they suggest that even if diacritics can be processed automatically as they are necessary for reading isolated words, they can also be overlooked when their presence becomes more gratuitous in connected sentences. That is, the results from Experiment 1 and 2 showed that context significantly reduced the effect of diacritics, but did not eliminate it altogether. Therefore, it appears that processing diacritics may not be entirely automatic (i.e., performed in an involuntary and obligatory manner), because it is reduced when the disambiguating information can be derived from the context and not only from the printed word. Still, although context makes reading much easier to understand, the readers are still sensitive to the phonological information provided by diacritics and make good use of it to improve comprehension, as required by the task’s conditions. Therefore, the contribution of diacritics can be considered as indispensible for naming and understanding single words, but it is additive to the contribution of context when processing written sentences, paragraphs, and texts (Abu-Rabia, 1997, 2001). This is because contextual cues can reduce the benefits of diacritics, by generating expectations for a certain word to appear in the text.

Moreover, previous evidence has found that the effects of diacritics differ between words and across tasks. While diacritics mainly facilitate naming (Frost, 1994; Koriat, 1984; Navon & Shimron, 1982) unless they constrain the less dominant meaning of a heterophone (Bentin and Frost, 1987), they do not clearly affect lexical decisions for unambiguous words (Bentin & Frost, 1987; Frost, 1994; Koriat, 1985; Navon & Shimron, 1985) and they might even hinder lexical decision to heterophonic homographs (Bentin & Frost, 1995). Data from semantic decision did not suggest that diacritics affect performance for unambiguous words (Navon & Shimron, 1985). Findings from this thesis indicate that diacritics improve comprehension of words but not uniformly. Results from Experiments 1 and 2 suggest that diacritics mostly benefit heterophonic homographs by disambiguating their phonology and hence their meaning. The reported beneficial effects of diacritics on reading comprehension in the literature (e.g., Abu-Leil, 2013; Abu-Rabia, 1997, 2001) seem therefore to be limited to the disambiguation of heterophonic homographs. This might be because for unambiguous words, the diacritics add up to the amount of phonological information provided, but do not significantly help in disambiguating the word that has only one way of being pronounced when it is presented without diacritics.

Hence, when one meaning of a homograph has to be accessed, diacritics appear to not only provide phonological information but to also help in disambiguating lexical meaning, thereby improving the probability of access to the specified meaning of the homograph. What is more, diacritics likely facilitate reading by cueing the subordinate meaning of the word that might not be available when the word is undiacritized (even if it is known by the reader). That is, when the dominant form of a homograph is associated with a non-living meaning (e.g., مَدْرَسَة */madrasat/ school*), lexical access to the word's living meaning (e.g., مُدَرِّسَة */mudarrisat/ teacher*) is more difficult to the reader, likely because the dominant meaning inhibits the subordinate meaning when the word is presented without diacritics (for a discussion of similar results in English, see Gottlob et al., 1999).

Finally, it appears that improving comprehension may exact a cost in processing time (Bourisly et al., 2012; Ibrahim, 2013; Roman & Pavard, 1987). The results from Experiment 1, 2, and 3 reported in this study showed that adding diacritics delays the comprehension of all sentences and of single unambiguous words. This hindering effect of diacritics may be explained by several underlying mechanisms.

One possible explanation is that an increase in perceptual noise or visual crowding (Roman & Pavard, 1987; Hermena et al., 2015) in which the added diacritics interfere with the surrounding letters, delays the uptake of visual information and therefore word recognition. It is important to note that Bourisly et al. (2013) indicated that diacritics delayed reading of words only and did not delay reading of non-words. Also, the data in Experiment 3 showed that adding diacritics to one word slowed the sentence almost as much as adding significantly more diacritics to the whole sentence, and that diacritization slowed the comprehension of unambiguous words but not ambiguous ones. Taken together, these results support the suggestion that although adding diacritics may delay reading by increasing the words' visual complexity, this visual aspect of diacritics is only one of the factors that might explain their hindering effects.

Another possible factor is the lack of familiarity of the skilled readers with the diacritized script. Indeed, even if readers of Arabic may encounter the diacritized script in the form of religious or literary material, they still read undiacritized script considerably more often in their daily lives. Thus, when reading the less familiar diacritized script, they might take more time to processes it. To test this possibility, Hermena (2015) did not document a change in processing diacritized sentences when familiarity increased across the duration of the experiment, but he certainly could not rule out the long-term effect of familiarity on reading diacritized sentences.

The most documented factor that might explain the slowing effects of diacritics is the difference in reading strategies between the diacritized and the undiacritized Arabic (Taouk & Coltheart, 2004; Ibrahim, 2013; Abu-Leil, 2014). When discussing reading strategies, no specific model of reading is emphasized in this thesis (e.g., DRC vs. triangle model, local vs. distributed representations). Instead the focus is on the relative importance of orthography versus phonology in the reading processes. As proposed by the orthographic depth hypothesis (Katz & Feldman, 1981; Feldman & Turvey 1983; Frost, Katz & Bentin, 1987; Katz Frost 1992), differences in grapheme-to-phoneme regularities between languages (i.e., deep versus shallow orthographies) encourage differential processing in reading. Namely, diacritized Arabic (that is a shallow orthography) supports more easily grapheme-to-phoneme translation to access meaning, while undiacritized Arabic (that is a deep orthography) encourage the readers to refer to the word's morphology via its visual-orthographic structure (Katz & Frost, 1992) to access meaning.

Thus, keeping the word undiacritized may facilitate word recognition by making the root and pattern of the word more salient, while at the same time leaving its phonological realization ambiguous. Shimron (2005) proposed that this "blessing of ambiguity" might explain why unvoweled Arabic has remained a viable orthography for such a long time. Conversely, the use of diacritics may encourage the readers to read words by using the more time-consuming indirect assembled phonological route instead of the more habitual lexical route (e.g., Coltheart et al., 2001). Although all reading must contain both visual/orthographic and phonological processing (for a discussion, see Seidenberg & McClelland, 1989; Van Orden et al., 1990; Carello, Turvey, & Lukatela, 1992; Besner, 1999), it is the relative involvement of these processes that varies between orthographies.

Overall, it appears that phonological and orthographic strategies are simultaneously at work, and it is the available data in the print, and the task requirements, that dictates the nature of the reading processes in Semitic reading (Shimron, 2006). Results from Experiment 4 in this thesis suggested that even when the word is presented phonologically complete (diacritized) thereby encouraging the reader to rely on phonology in reading it, its orthographic representation (i.e., the consonantal structure of the word without diacritics) remains active, and it affects access to the word's meaning. These findings support the suggestion that readers of Arabic still make use of the lexical route when accessing meaning, even in the reading of the shallow version of their orthography.

Is there an optimal diacritization for reading at the two extremes of orthographic depth?

Findings from Experiment 1 and 2 in this thesis suggest that readers of Arabic benefit from diacritics variably, depending on the written word's phonological ambiguity. When a word is phonologically ambiguous (i.e., heterophonic homograph), diacritics facilitate reading by making the meaning of the word (especially if it is less dominant) more readily available. In contrast, diacritics slow down reading when they complete the written word's phonology without providing it with any disambiguating benefit. Experiment 3 selectively diacritized all heterophonic words in a sentence, and examined how the reader's performance compared to fully diacritized and undiacritized sentences. The hypothesis was that selectively diacritizing the heterophonic homograph would take advantage of the facilitating effects of diacritics (i.e., improving comprehension of heterophonic homographs) without slowing down the rest of the sentence. The mixed results of Experiment 3 do not show a definite advantage to selectively diacritizing heterophonic homographs in a sentence, in comparison to diacritizing the whole sentence. However, selective diacritization is found to improve comprehension of an undiacritized sentence without slowing it down. Further, results suggest that diacritics aid comprehension by disambiguating only the subordinate meaning of the heterophone, while they do not improve comprehension when they indicate the dominant meaning of the word. Therefore, the practice of selectively diacritizing all the subordinate meanings of heterophonic homographs in a sentence is encouraged in writing Arabic, as it might prove to be efficient and economical because it phonologically clarifies those areas that might be otherwise ambiguous in a sentence.

How are phonologically ambiguous words (i.e., heterophonic homographs) accessed in Arabic?

One example of a heterophonic homograph in Arabic is the word عالم/ʕa:lm/ that can correspond to two different pronunciations and meanings when diacritized: عالَم /ʕa:lam/ world, or عالِم /ʕa:lim/ scientist. Findings from Experiment 1 in this thesis suggest that the readers are not always able to access (chiefly) the subordinate meaning of the phonologically ambiguous heterophonic homograph without diacritics (e.g. the scientist meaning of عالم /ʕa:lm/) even if they know it. Adding diacritics seems to help the reader in accessing the meaning of the word by fully identifying its pronunciation and therefore its meaning. Further, results from Experiment 4 indicate that even when only one meaning is clearly specified by the addition of diacritics (e.g., عالَم */ʕa:lam/ world*), the consonantal structure of the word (e.g., عالم */ʕa:lm/*) still activates its competing alternative (e.g., عالِم */ʕa:lim/ scientist*) in reading comprehension. That is, when the readers are asked if the phonologically unambiguous word عالَم */ʕaːlam/* world has a living meaning, they take generally more time and make more errors in doing so than when reading another word which consonantal structure corresponds two non living meanings when diacritized (e.g., شَعْر*//ʃaʕr/ hair*, شِعْر*//ʃiʕr/ poetry*). Also, the readers' performance is different between these two types of words only on a semantic categorization task, and not on a lexical decision, nor on a naming task.

Thus, the abstract phonologically incomplete consonantal structure of the word (e.g., عالم */ʕaːlm/)* as defined by Frost (1992, 1998, 2012) seems to be an important orthographic entity in reading for comprehension. Results from Experiment 4 suggest that both alternatives of a heterophonic homograph are activated when the reader recognizes this orthographic entity even when it is presented phonologically complete. Maintaining the two alternatives of a heterophonic homograph in working memory seems to reflect the strategies typically used by Arabic readers. This is because reading homographs in a phonologically incomplete script without diacritics is so common in Arabic that having to resolve phonological ambiguity is a routine procedure in everyday reading. Also, as the disambiguating context usually follows rather than precedes the phonologically ambiguous words, then the ultimate strategy for processing undiacritized heterophones might be for the readers to maintain their phonological alternatives in working memory until they reach the clarifying context and therefore select the appropriate meaning (see also for Hebrew, Frost & Bentin, 1992). Moreover, because the Arabic reader is familiar with reading undiacritized Arabic, then the strategies used for undiacritized Arabic might be still of use when reading diacritized Arabic.

Which model of reading is best suited to explain word recognition in Arabic?

This thesis primarily explored semantic access to words with and without diacritics. Therefore, both of these scripts will be taken into account when proposing an Arabic reading model (fig. 6.1) based on the current results as well as previous findings from the literature. Moreover, because results from Experiment 1 suggested that heterophones are understood differently from non-heterophones, the focus of this model will be on the processing of heterophonic homographs in Arabic. Modeling the access to those words that have the same orthography but different pronunciations may contribute to clarifying the more general roles of orthographic and phonological codes in Arabic word recognition.

The linguistic particularities of the Arabic script contradict certain aspects of traditional reading theory, and should be taken into account when designing a model of reading specific to Arabic. Most importantly, because of the lack of phonological information in written words, readers of Arabic have to rely on additional resources other than phonology such as context and morphology to decode and understand what is written. This makes reading more cognitively demanding in Arabic than in other orthographies such as English. For instance, results from Experiment 1 and 2 indicate that putting a heterophone in a sentence improved its comprehension, even when it is diacritized. This is likely because putting a word in a sentence guides the reader to one particular alternative of the heterophone and makes it easier to understand. More generally, it appears that context plays a more dominant role in Arabic than other languages (Abu-Rabia and Siegel 1995; Abu-Rabia 1997) because the reader has to infer the missing phonological information in the word from the external context. Therefore, the Arabic reader is largely dependent on context when trying to determine the meaning of heterophonic homographs.

Within this context-dependent semantic processing, especially when the context is ambiguous or unavailable, it appears that the reader gives additional priority to a particular version of a heterophone according to its dominance. In Experiment 1 for instance, the more a word had a subordinate meaning, the more it benefitted from the addition of diacritics. This suggests that even if the reader knows the subordinate meaning of a heterophone when s/he sees it without diacritics, s/he tends to read it as the most frequent dominant one. In this case, diacritics allow the readers to activate a semantic representation that they would not have been able access from a word without diacritics alone.

When a heterophone is diacritized as in in Experiment 4, RTs were longer when the word's meanings were unrelated, suggesting that both meanings of a heterophonic homograph are activated, even when one phonological alternative is clearly specified. What is more, even when both those meanings are initially activated, accuracy scores indicate that the dominant meaning that is associated with the word's consonantal structure sometimes inhibit the meaning of the presented word with diacritics making the responses less accurate.

Therefore, it seems that in Experiment 4 the consonantal structure of the word has sometimes guided participants in the direction of an incorrect response despite the presence of diacritics. In other words, even when an Arabic word was made phonologically and semantically clear by full diacritization, the phonologically incomplete consonantal structure of the word sometimes appears to have been used to access the word's meaning, This outcome provides further evidence of the key role that mental representations of written consonantal sequences play in identifying words in Semitic orthographies (Frost,1987, 1992. 1998). Frost and Bentin (1987, 1992) had previously suggested that lexical access in Hebrew is based on an abstract interface representation that is not phonologically detailed: the consonantal structure of the word without its superimposed diacritics. Note that since the proficient Arabic-readers typically read undiacritized script in their daily life, they are more accustomed to reading words without diacritics and hence to seeing both versions of the heterophonic homograph as the consonantal entity defined by Frost and Bentin. This additional abstract layer of orthographic processing appears primordial in understanding how readers access meaning when reading Arabic script. It suggests that the abstract morpho-orthographic representation of a word can be used to access meaning. In the model we will use, all resources (orthography, morphology, context, and diacritics) are useful in semantic access. According to this model, the reader encounters a heterophone (ambiguous without diacritics or unambiguous with diacritics), detracts the consonantal structure, and considers both the diacritics and the surrounding context before making a semantic decision.

The model is presented in figure 6.1.

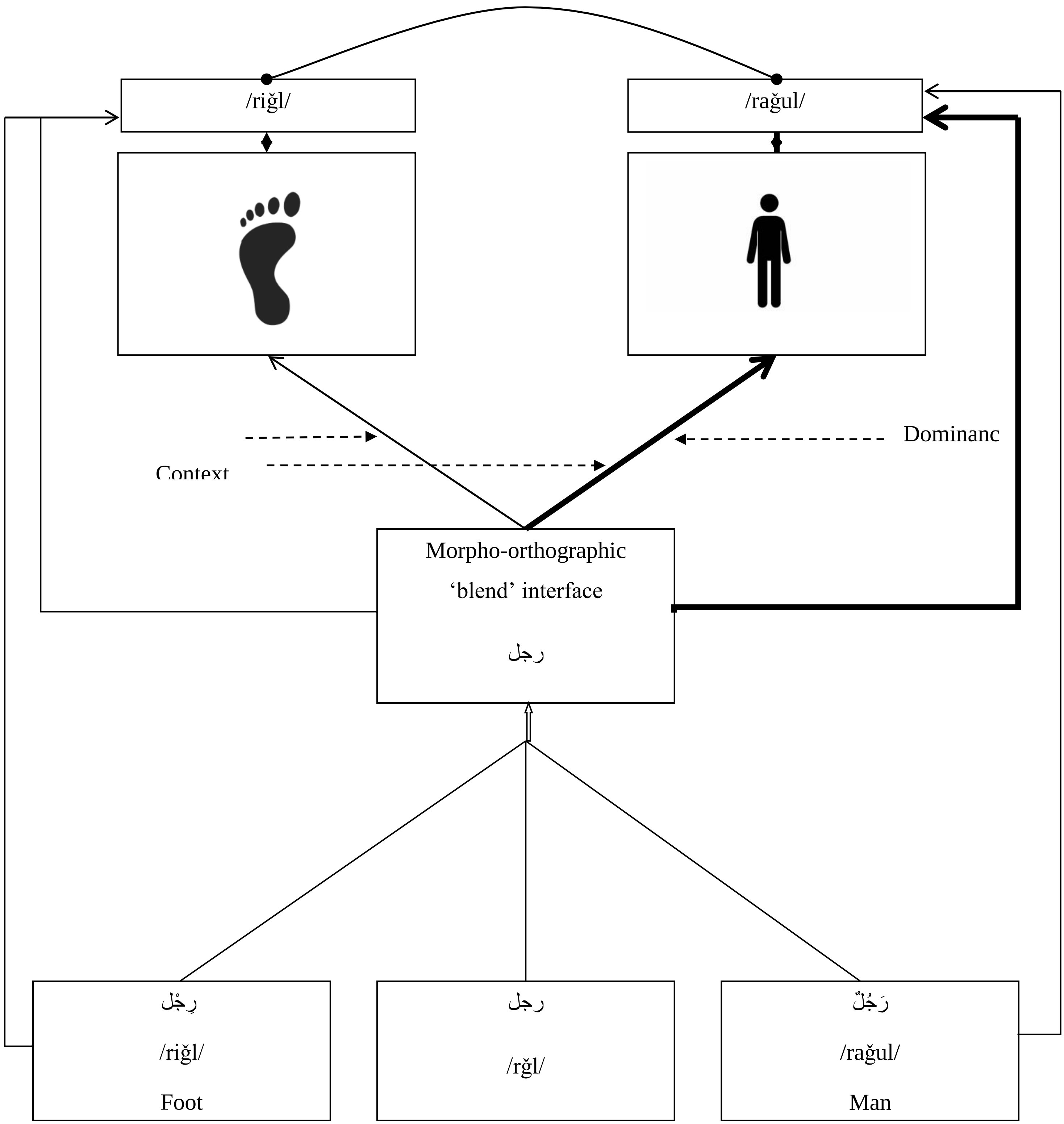

Figure 6.1 A model of reading heterophonic homographs in Arabic.

According to this model, when readers are presented with an undiacritized word (رجل /rğl/), they can go through a lexical route in which the morpho-orthographic interface is activated (رجل /rğl/). This entity strongly activates the dominant semantic representation (رَجلُ /rağul/ man), while the subordinate semantic representation is weakly activated (رِجْل /riğl/ foot). The pronunciation of /rağul/ is generated if the context is appropriate for a man or there is no context, and so the meaning of *foot* will be inhibited. Alternatively, the pronunciation of /riğl/ is generated only if the context is appropriate for a *foot* meaning; the meaning *man* will be inhibited in this case. Therefore, the lexical route can produce fast access to the dominant meaning on a semantic decision task and slower access to its associated subordinate meaning. Evidently, no nonlexical activation occurs in the absence of vowelization, as readers cannot assemble phonology from the vowel-missing orthography.

On the other hand, when the diacritized word with a subordinate meaning (رِجْل /riğl/ foot) is presented to the readers, they can go through two routes. In the lexical route, the morpho-orthographic entity is activated, and therefore both pronunciations may be available, with the competing meaning (رَجُلٌ /rağul/ man) being more strongly activated. Here, the answer may be quick, but it is often inaccurate in a semantic decision task. In opposition, the non-lexical routes may produce slow but accurate responses on a semantic decision or a spoken naming task. Because the readers have access to the full pronunciation of the word, they can produce it by a letter/diacritic-phoneme conversion. However, they may take more time in doing so, because they have to inhibit the inconsistent pronunciation /rağul/ generated by the lexical route.

6.4 Directions for Future Research

The present research adds to the evidence that written Arabic is a cognitively complex language. Although the experiments in this thesis were not designed to determine the varying effects of diacritics in relation to the dominance of the word, meaning bias appeared to be an important factor to consider when studying the effect of diacritics on reading comprehension. The correlations found between the dominance of the word and the performance of the reader suggested that the less a meaning is dominant the less accurately it is understood and the more it benefits from the addition of diacritics. However, it did not determine whether additional factors such as the frequency of the word were also involved in these effects. When correlations are used to examine the effects of dominance on the influence of diacritics, it is difficult to draw any strong conclusions. The problem is that other variables that have not been controlled may be partly or fully responsible for any observed differences. For example it may be that words with greater dominance are also lower in age of acquisition or higher in frequency and that it is in fact the age of acquisition of the word that is the main factor that modulates the effects of diacritics on word comprehension. Therefore, future factorial research that controls for the words' characteristics including meaning bias is still needed to further investigate the contribution of diacritics to reading. Relevant factors include age of acquisition, imageability, typicality, density of semantic neighbors, frequency, etc.

Moreover, results from Experiments 1 and 2 and from previous studies (Roman et al., 1985; Abu-Rabia and Siegel 1995; Abu-Rabia 1997, 1998, 2001) suggest that the role of context is more important in Arabic than in other languages, especially with regards to the contribution of diacritics. In Experiment 2, words were placed in sentences without specifiying the characteristics of these sentences further. It would be interesting to conduct additional research on the role of diacritics in which sentence-properties would be matched and manipulated. For instance, future research might look in more depth into whether the location of the ambiguous word in the sentence would affect how much its processing is impacted by diacritics. A word placed at the beginning of the sentence likely benefits from diacritics more than a word placed at the end of the sentence. At the beginning of the sentence, the reader does not have expectations for the word to come and s/he needs additional phonological information to guess which alternative of a heterophonic homograph s/he is reading. Conversely, when the word is at the end of the sentence, the reader can take advantage from the cues of the context to constraint the number of possible options and determine the appropriate version of the ambiguous word s/he is reading without needing additional phonological information. Also, the number of ambiguous words in the sentence and the length of the sentence might modulate the effects of diacritics on reading. In Experiment 2 and 3, the length of the sentence was not taken into consideration when designing the experiment. Future research can match sentence-length to determine for example whether the impact of diacritics changes when more contextual information is provided to the reader by longer sentences.

In addition, it must be acknowledged that a limitation of the present study is that the proficiency of the participants in Arabic was not measured when the study was carried out. Although they were all native speakers of Arabic, the participants were university students who spent a lot of time reading in their second language (English or French). It would be interesting to discover whether similar results would be observed with monolingual speakers who read the Arabic script exclusively. What is more, results with monolingual speakers who read primarily diacritized Arabic (Quran) would also be of particular interest.

Moreover, the previous studies provided valuable information on the processes involved in reading Arabic by recording the readers' performance (time course and accuracy) on widely used experimental paradigms like lexical decision, naming, semantic decision, and sensicality judgment. They did not however allow for a full understanding of the stages that are involved in reading, nor did they measure the brain activity of the reader while performing these tasks. In addition to the behavioral methods used in this thesis, other techniques such as event-related brain potentials (ERPs) can assess more precisely real-time brain neural activity when reading; they can be used in future research to provide a more comprehensive understanding of the neurocognitive processes involved in understanding words and sentences in Arabic.

Finally, the use of diacritics being by definition primarily restricted to developing readers, studying the changing role of diacritics across time could prove very informative. Specifically, the investigation of the way developing readers transition from fully diacritized texts to undiacritized texts might provide great insights on the contribution of phonology, orthography, and context to the development of learning to read in Arabic. For instance, readers in grade 5 who are used to reading with diacritics, but who are unfamiliar with the undiacritized script may be asked to perform the tasks presented in this thesis. A comparison between their results and those reported in this thesis for proficient readers who are conversely familiar with the undiacritized but not the diacritized orthography can provide a fuller picture of the contribution of diacritics to reading comprehension. Developing readers may not be delayed by the addition of diacritics, as they are used to decoding words with diacritics, and they may not show the effect of meaning similarity found in Experiment 4, because young Arabic readers may not have fully developed a proficient lexical route in reading. An important factor to consider in future analyses is that proficient readers of Arabic seem to benefit more from contextual information than less proficient readers (Roman et al., 1985; Abu-Rabia and Siegel 1995; Abu-Rabia 1997, 1998, 2001), in contrast with the widely accepted theory that only poor readers need to rely on context in order to compensate for their less developed decoding skills (Stanovich 1980, 2000) in English,. Thus, it might be that the more readers of Arabic become skilled in reading the less they rely on phonology and the more they rely on context. It would be then interesting to investigate whether the effect of diacritics on word and sentence comprehension weakens over time as the reader becomes more expert in decoding. Also, determining if the developing reader progresses through stages in 'diacritic development' during the process of becoming a proficient reader across school grades might pose an interesting challenge to future researchers.

7 Appendix

7.1 Words of Experiment 1

Ambiguous diacritized words	Ambiguous undiacritized words	Unambiguous diacritized words	Unambiguous undiacritized words
السِلّق	السلق	الحَجَل	الحجل
المُعَلِّم	المعلم	البَغْل	البغل
الحَدَّاد	الحداد	التِلْمِيذ	التلميذ
المُقَاوِمَة	المقاومة	الأَفْطَس	الأفطس
الصَبَّاغ	الصباغ	الأَسَد	الأسد
الحَمَام	الحمام	الشَهِيد	الشهيد
البَشَر	البشر	الفَنَّان	الفنان
الخَرِف	الخرف	الخَبَّاز	الخباز
العَالِم	العالم	الصَّقِر	الصقر
المُهْر	المهر	العَجُوز	العجوز
الجَزَر	الجزر	الفَهْد	الفهد
الخَيَّال	الخيال	السِنْدِيَان	السنديان
البَزَّاق	البزاق	البُلْبُل	البلبل
المُتَنَزِّه	المتنزه	البَطَّة	البطة
السَبَّاحَة	السباحة	الفُجْل	الفجل
الذُرَة	الذرة	الشَخْص	الشخص
البَطَل	البطل	البَصَل	البصل
المَلِك	الملك	التَاجِر	التاجر
الحَمَل	الحمل	الأَسِير	الأسير
المُنَجِّم	المنجم	السُنُونُو	السنونو
الجَد	الجد	العِجْل	العجل
المُدَرِّسَة	المدرسة	الشَاه	الشاه
الخَيَّاطَة	الخياطة	العَتَّال	العتال
النَوَر	النور	النَسْر	النسر
النَحَّاس	النحاس	الجَوْز	الجوز
المُبَلِّغ	المبلغ	الفُلْفُل	الفلفل
الفُطّر	الفطر	الفَرَّان	الفران
المُحَاضِرَة	المحاضرة	الشَاعِر	الشاعر
الحَصَّاد	الحصاد	الجَرُو	الجرو
المُهَاجِر	المهاجر	الحَطَّاب	الحطاب
الجَمَل	الجمل	الطَاهِ	الطاه
البَنَّاء	البناء	البَنَدُورَة	البندورة
الحَكَم	الحكم	الشَمَّام	الشمام
المُخْرِج	المخرج	العِنَب	العنب
المُدَخِّنَة	المدخنة	الثُوم	الثوم
الكَلِب	الكلب	البَلَح	البلح
السَمَك	السمك	التُفَّاحَة	التفاحة
الرَجُل	الرجل	الفَرَاشَة	الفراشة
النِمْر	النمر	الدُرَّاق	الدراق

السنجاب	السِنْجَاب	الخلف	الخَلَف

7.2 Sentences of Experiment 2

Ambiguous diacritized	Ambiguous undiacritized
ذَبُلَ السِلْقُ المَقْطُوفُ	ذبل السلق المقطوف
إِجْتَمَعَتِ المُدَرِّسَةُ بِزُمَلائِهَا	إجتمعت المدرسة بزملائها
صَنَعَ الحَدَّادُ بَوَّابَةً	صنع الحداد بوابة
إِنضَمَّتِ المُقَاوِمَةُ إِلى رِفَاقِهَا	إنضمت المقاومة إلى رفاقها
سَلَّمَ الصَبَّاغُ الثِيابَ لِلزَبُونِ	سلم الصباغ الثياب للزبون
حَطَّ الحَمَامُ عَلَى النَافِذَةِ	حط الحمام على النافذة
أَحْرَقَ البَشَرُ غَابَاتِ الصَنَوْبَرِ	أحرق البشر غابات الصنوبر
دَخَلَ الخَرِفُ إِلَى المَصَحِّ	دخل الخرف إلى المصح
أَثْبَتَ العَالِمُ نَظَرِيَّةً جَدِيدَةً	أثبت العالم نظرية جديدة
رَكَضَ المُهْرُ فِي البَرِّيَّةِ	ركض المهر في البرية
إِمْتَصَّ الجَزَرُ المَاءَ مِنَ التُرْبَةِ	إمتص الجزر الماء من التربة
إِمْتَطَى الخَيَّالُ الجَوَادَ	إمتطى الخيال الجواد
ظَهَرَالبَزَّاقُ بَعْدَ المَطَرِ	ظهرالبزاق بعد المطر
جَالَ المُتَنَزِّهُ فِي الطَبِيعَةِ	جال المتنزه في الطبيعة
أَقْلَعَتِ المُدَخِّنَةُ عَنْ عَادَاتِهَا	أقلعت المدخنة عن عاداتها
سَلَقَتِ الأُمُّ الذُرَةَ	سلقت الأم الذرة
إِبْتَلَعَ السَمَكُ فُتَاتَ الخُبْزِ	إبتلع السمك فتات الخبز
أَعْدَمَ المَلِكُ الثُوَّارَ	أعدم الملك الثوار
شَرِبَ الحَمَلُ مِنَ الدَلْوِ	شرب الحمل من الدلو
أَخَذَ الخَلَفُ أَمْوَالَ وَالِدِهِ	أخذ الخلف أموال والده
كَتَبَ الجَدُّ وَصِيَّتَهُ	كتب الجد وصيته
شَرَحَ المُعَلِّمُ الدَرْسَ	شرح المعلم الدرس
قَدَّرَتِ الخَيَّاطَةُ مَقَاسَ البِنْطَالِ	قدرت الخياطة مقاس البنطال
رَبَطَ النَوَرُ خِيَامَهُمْ	ربط النور خيامهم
بَاعَ النَحَّاسُ قِطْعَةً مِنَ الخُرْدَةِ	باع النحاس قطعة من الخردة
أَخْبَرَنَا المُبَلِّغُ خَبَراً حَزِيناً	أخبرنا المبلغ خبرا حزينا
نَضَجَ الفُطْرُ فِي الحَقْلِ	نضج الفطر في الحقل
نَاقَشَتِ المُحَاضِرَةُ الطُلاَّبَ	ناقشت المحاضرة الطلاب
جَمَعَ الحَصَّادُ المَحْصُولَ	جمع الحصاد المحصول
قَبَّلَ المُهَاجِرُ أَرْضَ وَطَنِهِ	قبل المهاجر أرض وطنه
حَمَلَ الجَمَلُ الصَنَادِيقَ عَلَى ظَهْرِهِ	حمل الجمل الصناديق على ظهره
طَبَعَ البَنَّاءُ الخَرَائِطَ	طبع البناء الخرائط
صَفَّرَ الحَكَمُ عِنْدَ إِنْتِهَاءِ المُبَارَيَاتِ	صفر الحكم عند انتهاء المباريات
صَوَّرَ المُخْرِجُ الوَثَائِقِيَّ	صور المخرج الوثائقي
وَصَلَتِ السَبَّاحَةُ إِلَى خَطِّ النِهَايَةِ	وصلت السباحة إلى خط النهاية
يَحْرُسُ الكَلْبُ المَنْزِلَ	يحرس الكلب المنزل
أَخَذَ البَطَلُ دِرْعًا تَكْرِيمِيًّا	أخذ البطل درعا تكريميا
إِقْتَنَى الرَجُلُ سَيَّارَةً	إقتنى الرجل سيارة
إِنْقَضَّ النَمِرُ عَلَى فَرِيسَتِهِ	إنقض النمر على فريسته
عَرَضَ المُنَجِّمُ تَوَقُّعَاتِهِ	عرض المنجم توقعاته

Unambiguous diacritized	Unambiguous undiacritized
حَطَّ الحَجَلُ عَلَى غُصْنِ الشَجَرَةِ	حط الحجل على غصن الشجرة
رَكَضَ البَغْلُ فِي المَزْرَعَةِ	ركض البغل في المزرعة
دَخَلَ التِلْمِيذُ إِلَى قَاعَةِ الإِمْتِحَانِ	دخل التلميذ إلى قاعة الإمتحان
قَصَّ الأَفْطَسُ شَعْرَهُ	قص الأفطس شعره
هَجَمَ الأَسَدُ عَلَى فَرِيسَتِهِ	هجم الأسد على فريسته
مَاتَ الشَهِيدُ فِي المَعْرَكَةِ	مات الشهيد في المعركة
عَزَفَ الفَنَّانُ عَلَى الآلَةِ المُوسِيقِيَّةِ	عزف الفنان على الآلة الموسيقية
صَنَعَ الخَبَّازُ الخُبْزَ	صنع الخباز الخبز
طَارَ الصَقْرُ فِي السَمَاءِ	طار الصقر في السماء
كَسَرَ العَجُوزُ وِرْكَهُ	كسر العجوز وركه
طَارَدَ الفَهْدُ الغَزَالَ	طارد الفهد الغزال
إِحْتَرَقَ السِنْدِيَانُ فِي الغَابَةِ	إحترق السنديان في الغابة
زَقْزَقَ البُلْبُلُ دَاخِلَ القَفَصِ	زقزق البلبل داخل القفص
قَفَزَتِ البَطَّةُ فِي البِرْكَةِ	قفزت البطة في البركة
نَبَتَ الفِجْلُ فِي الحَقْلِ	نبت الفجل في الحقل
ذَهَبَ هَذَا الشَخْصُ إِلَى المَدِينَةِ	ذهب هذا الشخص إلى المدينة
يُثِيرُ البَصَلُ الدُمُوعَ	يثير البصل الدموع
بَاعَ التَاجِرُ البَضَائِعَ	باع التاجر البضائع
خَرَجَ الأَسِيرُ مِنَ المُعْتَقَلِ	خرج الأسير من المعتقل
هَاجَرَ السُنُونُو فِي الخَرِيفِ	هاجر السنونو في الخريف
أَكَلَ العِجْلُ العُشْبَ	أكل العجل العشب
وَضَعَ الشَاهُ التَاجَ عَلَى رَأْسِهِ	وضع الشاه التاج على رأسه
حَمَلَ العَتَّالُ الْأَكْيَاسَ عَلَى ظَهْرِهِ	حمل العتال الأكياس على ظهره
حَلَّقَ النَسْرُ فِي السَمَاءِ	حلق النسر في السماء
سَقَطَ الجَوْزُ عَنِ الشَجَرَةِ	سقط الجوز عن الشجرة
نَضَجَ الفُلْفُلُ فِي الحَقْلِ	نضج الفلفل في الحقل
خَلَطَ الفَرَّانُ الطَحِينَ مَعَ المَاءِ	خلط الفران الطحين مع الماء
أَلْقَى الشَاعِرُ قَصِيدَةً	ألقى الشاعر قصيدة
نَبَحَ الجَرْوُ قُرْبَ البَيْتِ	نبح الجرو قرب البيت
جَمَعَ الحَطَّابُ الخَشَبَ	جمع الحطاب الخشب
حَضَّرَ الطَاهِي العَشَاءَ	حضر الطاهي العشاء
نَبَتَتِ البَنَدُورَةُ دَاخِلَ الخِيَمِ	نبتت البندورة داخل الخيم
أَصْبَحَ الشَمَّامُ جَاهِزاً لِلْحَصَادِ	أصبح الشمام جاهزا للحصاد
إِسْتَوَى العِنَبُ عَلَى الدَوَالِي	إستوى العنب على الدوالي
يَبِسَ الثُومُ فِي الأَرْضِ	يبس الثوم في الأرض
جَفَّ البَلَحُ عَلَى الشَجَرَةِ	جف البلح على الشجرة
وَقَعَتِ التُفَّاحَةُ تَحْتَ الشَجَرَةِ	وقعت التفاحة تحت الشجرة
رَفْرَفَتِ الفَرَاشَةُ فَوْقَ الأَزْهَارِ	رفرفت الفراشة فوق الأزهار
وَقَعَ الدُرَّاقُ عَلَى الأَرْضِ	وقع الدراق على الأرض
تَسَلَّقَ السِنْجَابُ الشَجَرَةَ	تسلق السنجاب الشجرة

7.3 Sentences of Experiment 3

Fully diacritized	Undiacritized	Selectively diacritized
يَذْبُلُ السِلْقُ على الطَاوِلَةِ	يذبل السلق على الطاولة	يذبل السِلْقُ على الطاولة
إجْتَمَعَتْ المُدَرّسَةُ بِزُمَلائِهَا	إجتمعت المدرسة بزملائها	إجتمعت المُدَرِّسَةُ بزملائها
يَصْنعُ الحَدَّادُ بَوَّابَةً	يصنع الحداد بوابة	يصنع الحَدَّادُ بوابة
إنْضَمَّتِ المُقَاوِمَةُ إلى رِفَاقِهَا	إنضمت المقاومة إلى رفاقها	إنضمت المُقَاوِمَةُ إلى رفاقها
أَعْطَى الصَّبَّاغُ الثِّيَابَ لِلْزُبُونِ	أعطى الصباغ الثياب للزبون	أعطى الصَّبَّاغُ الثياب للزبون
طَارَ الحَمَامُ مِنَ النَّافِذَةِ	طار الحمام من النافذة	طار الحَمَامُ من النافذة
أَحْرَقَ البَشَرُ غَابَاتَ الصَنُوبَرِ	أحرق البشر غابات الصنوبر	أحرق البَشَرُ غابات الصنوبر
إنْضَمّ الخَرِفُ إلى المَصَحّ	إنضم الخرف إلى المصح	إنضم الخَرِفُ إلى المصح
أَثْبَتَ العَالِمُ نَظَرِيَّةً جَدِيدَةً	أثبت العالم نظرية جديدة	أثبت العَالِمُ نظرية جديدة
إنْطَلَقَ المُهْرُ فِي البَرّيَّةِ	إنطلق المهر في البرية	إنطلق المُهْرُ في البرية
إمْتَصَّ الجَزَرُ المَاءَ مِنَ التُرْبَةِ	إمتص الجزر الماء من التربة	إمتص الجَزَرُ الماء من التربة
إمْتَطَى الخَيَّالُ الجَوَادَ	إمتطى الخيال الجواد	إمتطى الخَيَّالُ الجواد
يَظْهَرُ البَزَّاقُ بَعْدَ المَطَرِ	يظهر البزاق بعد المطر	يظهر البَزَّاقُ بعد المطر
جَالَ المُتَنَزِّهُ فِي الطَّبِيعَةِ	جال المتنزه في الطبيعة	جال المُتَنَزِّهُ في الطبيعة
أَقْلَعَتِ المُدَخِّنَةُ عَنْ عَادَتِهَا	أقلعت المدخنة عن عاداتها	أقلعت المُدَخِّنَةُ عن عاداتها
أَكَلَتِ الأُمُّ الذُّرَةَ	أكلت الأم الذرة	أكلت الأم الذُّرَةَ
إبْتَلَعَ السَّمَكُ فُتَاتَ الخُبْزِ	إبتلع السمك فتات الخبز	إبتلع السَّمَكُ فتات الخبز
أَعْدَمَ المَلِكُ الثُّوَّارَ	أعدم الملك الثوار	أَعْدَمَ المَلِكُ الثوار
يَشْرَبُ الحَمَلُ مِنَ الدَّلوِ	يشرب الحمل من الدلو	يشرب الحَمَلُ من الدلو
وَرَثَ الخَلَفُ أَمْوَالَ والِدِهِ	ورث الخلف أموال والده	ورث الخَلَفُ أموال والده
أَعْطَى الجَدُّ وَصِيَّتَهُ	أعطى الجد وصيته	أعطى الجَدُّ وصيته
يَشْرَحُ المُعَلِّمُ الدَّرْسَ	يشرح المعلم الدرس	يشرح المُعَلِّمُ الدرس
قَصَّتِ الخَيَّاطَةُ البِنْطَالَ	قصت الخياطة البنطال	قصت الخَيَّاطَةُ البنطال
يَنْصِبُ النَّوَرُ خِيَامَهُمْ	ينصب النور خيامهم	ينصب النَّوَرُ خيامهم
بَاعَ النَّحَّاسُ قِطْعَةً مِنَ الخِرْدَةِ	باع النحاس قطعة من الخردة	باع النَّحَّاسُ قطعة من الخردة
أَخْبَرَنَا المُبَلِّغُ خَبَراً حَزِيناً	أخبرنا المبلغ خبرا حزينا	أَخْبَرَنَا المُبَلِّغُ خبرا حزينا
يَنْضُجُ الفُطْرُ فِي الحَقْلِ	ينضج الفطر في الحقل	ينضج الفُطْرُ في الحقل
نَاقَشَتِ المُحَاضِرَةُ الطُّلَّابَ	ناقشت المحاضرة الطلاب	ناقشت المُحَاضِرَةُ الطلاب
قَصَّ الحَصَّادُ المَحْصُولَ	قص الحصاد المحصول	قص الحَصَّادُ المحصول
عَادَ المُهَاجِرُ إلى وَطَنِهِ	عاد المهاجر إلى وطنه	عاد المُهَاجِرُ إلى وطنه
يَحْمِلُ الجَمَلُ الصَّنَادِيقَ عَلَى ظَهْرِهِ	يحمل الجمل الصناديق على ظهره	يحمل الجَمَلُ الصناديق على ظهره
يَبْنِي البَنَّاءُ البَيْتَ	يبني البناء البيت	يبني البَنَّاءُ البيت
أَعْلَنَ الحَكَمُ إنْتِهَاءَ المُبَارَيَاتِ	أعلن الحكم إنتهاء المباريات	أعلن الحَكَمُ إنتهاء المباريات
يُصَوِّرُ المُخْرِجُ الوَثَائِقِيَّ	يصور المخرج الوثائقي	يصور المُخْرِجُ الوثائقي
وَصَلَتِ السَّبَّاحَةُ إلى خَطِّ النِّهَايَةِ	وصلت السباحة إلى خط النهاية	وصلت السَّبَّاحَةُ إلى خط النهاية
يَحْرُسُ الكَلْبُ المَنْزِلَ	يحرس الكلب المنزل	يَحْرُسُ الكَلْبُ المنزل
يَأْخُذُ البَطَلُ دَرْعاً تَكْرِيمِيًّا	يأخذ البطل درعا تكريميا	يأخذ البَطَلُ درعا تكريميا

إقتنى الرَّجُلُ سيارة	إقتنى الرجل سيارة	إِقْتَنَى الرَّجُلُ سَيَّارَةً
إِنْقَضَّ النَمِرُ على فريسته	إنقض النمر على فريسته	إِنْقَضَّ النَّمِرُ عَلَى فَرِيسَتِهِ
يتكلم المُنَجِّمُ عن توقعاته	يتكلم المنجم عن توقعاته	يَتَكَلَّمُ المُنَجِّمُ عَنْ تَوَقُّعَاتِهِ

7.4 Words of Experiments 4-5-6

Vowelized heterophones with a non-living meaning that may have a living meaning	**Vowelized heterophones with a non-living meaning that may have another non- living meaning**
الخَلْف	السُحَاب
السَّلْق	السُكْر
الجِدَاد	البِرْكَة
النَّور	المَرْكَب
المَبْلَغ	المُرَبّى
البِشْر	القِدْر
الصِبَاغ	الشَعْر
المُتَنَزَّه	الدَرَجَة
السِبَاحَة	السِكّينَة
البُطْل	الدُرْج
البُزَاق	البَيْعَة
الخِيَاطَة	الحُجْرَة
الخَرَف	الشُبَّاك
المَنْجَم	الحَرَام
المَعْلَم	الثُمْن
الخَيَال	الذَنْب
العَالَم	السِحْر
المَهِر	الطَرْش
النُحَاس	الظَهْر
المَخْرَج	العِشْرَة
الحَصَاد	اللِبْس

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