# Diacritics improve comprehension of the Arabic script by providing access to the meanings of heterophonic homographs

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## Abstract

The diacritical markers that represent most of the vowels in the Arabic orthography are generally omitted from written texts. Previous research revealed that the absence of diacritics reduces reading comprehension performance even by skilled readers of Arabic. One possible explanation is that many Arabic words become ambiguous when diacritics are missing. Words of this kind are known as heterophonic homographs and are associated with at least two different pronunciations and meanings when written without diacritics. The aim of the two experiments reported in this study was to investigate whether the presence of diacritics improves the comprehension of all written words, or whether the effects are confined to heterophonic homographs. In Experiment 1, adult readers of Arabic were asked to decide whether written words had a living meaning. The materials included heterophonic homographs that had one living and one non-living meaning. Results showed that diacritics significantly increased the accuracy of semantic decisions about ambiguous words but had no effect on the accuracy of decisions about unambiguous words. Consistent results were observed in Experiment 2 where the materials comprised sentences rather than single words. Overall, the findings suggest that diacritics improve the comprehension of heterophonic homographs by facilitating access to semantic representations that would otherwise be difficult to access from print.

## 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 limited information about the identity of the vowels in written words. Additional studies of the ways in which readers process a script of this kind can therefore enrich our understanding of both the universal and the language-specific principles of reading.

***Arabic Orthography***. Arabic uses an alphabetic orthography that contains 28 letters. Apart from three letters that can represent both consonants and long vowels, /ا/,ā, /و/, ū, /ي/, ī/, Arabic letters represent consonants. Diacritical marks that appear above or below the body of the word are used to represent short vowels. In addition to vowel diacritics, shaddah /ّ/is a diacritic that appears above the letter to mark consonant gemination, equivalent to doubling the letter in orthographies that use the Roman alphabet.

In the presence of diacritics, Arabic is a transparent orthography. However, diacritical marks are absent from most printed material in the Arab world. This means that many words in Arabic texts are written as sequences of consonants or are only partially vowelized. 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 four to six years of primary school education. For further information about the Arabic orthography, see Saiegh-Haddad and Henkin-Roitfarb (2014).

***Effects of diacritics.*** 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. 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-Liel, Share, & Ibrahim (2014) and Ibrahim (2013) 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, 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). Abu-Rabia (2001) investigated the influence of diacritics and sentence context on reading accuracy and comprehension among skilled adult readers of Arabic. Participants were asked to read a list of single words, a paragraph and a short story in both the presence and absence of diacritics. 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-Liel et al. (2014) also showed that the presence of diacritics significantly improved the ability of skilled adult 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. The two experiments that are reported below 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 vowelized according to its grammatical function in written sentences. Although it would appear possible that diacritics make syntactic processing easier for readers of Arabic, the vowelization 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. Words of this kind are known as *heterophonic homographs* and include nouns, verbs and conjunctions. Heterophonic homographs also exist in other alphabetic orthographies (e.g. *a tear* in English), but they are much 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*).

**The purpose of the present study.** To date, the effects of diacritics on the disambiguation of heterophonic homographs when reading Arabic have not been studied directly. The aim of the two experiments reported in this study 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 unvowelized or partially vowelized form of a word will often be more familiar than its fully vowelized version. The vowelized 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-Liel, 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. We were particularly interested in 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-Liel 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. We therefore collected pilot data about the dominance of the living meaning of each of the homographs and subsequently examined the relationship between meaning dominance and performance on the semantic decision task.

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 homograph. 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 non-lexical 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.

## EXPERIMENT 1

### Method

#### *Participants*

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 to 26 years. 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.

#### *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 nonliving 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./alm/العـــالم which is associated with two different vowelized words /alim/ العَالِم scientist and /alam/العَالَم world). Occasionally a diacritic also provided information about gemination (e.g. /hmam/الحمـام which is associated with two different words /hammam/ امالحَمَّ toilet and /hamam/ الحَمَام pigeon).

The first pilot study was designed to estimate the subjective familiarity of this pool of written words. Ten 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 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 ten 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 nonliving. 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 ten 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 nonliving) 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 nonliving 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

**Insert Table 1 about here**

***Procedure***

Stimuli were presented on a laptop computer via e-prime using a powerpoint presentation. Participants were tested individually. All the participants were presented with two similar 160-word lists (set x and set z) in Arial size-66 font that. 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. The participants were instructed to look at a cross in the middle of the screen between stimuli. They were told to press a key if the word that appeared could represent a living thing, or to press another key if it could not represent a living thing. Words were presented in a random order. Words were presented with diacritics in a standard form similar to that found in a widely used dictionary.

**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 Figures 1 and 2.

**Insert Figure 1 and 2 about here**

***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 ($M$=34.3/40) than without diacritics ($M$=27.4/40). 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. These analyses 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 msecs) than without diacritics ($M$=1369 msecs). These findings are consistent with previous research on the effects of diacritics on reading speed in Arabic and Hebrew (Abu-Liel, et al, 2014; Bourisly et al., 2013). It seems likely that reaction times were significantly longer because diacritics provide additional visual information to be processed by readers before semantic decisions could be made.

**Insert Table 2 about here**

***Effects of familiarity and dominance*:** Table 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 on the living/non-living task.

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 vowelized. 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. 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.

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.

**Summary:** 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.

## 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. In

Experiment 2, therefore, we examined the processing of ambiguous Arabic words when they were embedded in a sentence.

## Method

### *Participants*

The participants were 50 undergraduate students drawn from the same population as Experiment 1. None of them had participated in Experiment 1.

### *Materials and Procedure*

Participants were shown 160 sentences one at a time and had to decide whether each sentence was meaningful. Half of the sentences were presented with diacritics and half were presented without diacritics. 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.

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.

Participants were tested individually. The sentences were presented in a different random order for each participant. The participants were instructed to look at a cross in the middle of the screen between stimuli, and to press a key if the sentence they then saw was meaningful, or to press another key if it was not meaningful. Examples of sentences used in the Experiment can be seen in Table 3.

**Insert Table 3 about here**

**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) than on sentences without diacritics ($M$=16.2), $F(1, 49) = 14.35$, $p < 0.001$, effect size = 0.8. Participants also had significantly slower reaction times to sentences containing diacritics ($M$=3057 msecs.) than to sentences without diacritics ($M$=2678 msecs.), $F(1, 49) = 10.02$, $p = .003$, 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 msecs.) than without diacritics ($M$=2259 msecs), $F(1, 49) = 13.95$, $p < 0.001$, effect size = 0.3). The effects of diacritics on RTs and accuracy scores are summarized in Figure 3.

**Insert Figure 3 and 4 about here**

***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. Performance with ambiguous items and unambiguous items were examined in separate analyses.

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 ambiguous words. The effect of type of stimuli (words vs. sentences) on accuracy for ambiguous words 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 ($M$=16.87), than when shown as single words ($M$= 15.41). The interaction between diacritics and type of stimuli was also significant $F(1, 98) = 35.82$, $p < .0001$). Additional analyses were conducted to investigate the nature of the interaction by examining the accuracy difference when ambiguous stimuli were presented with and without diacritics. The results revealed that the accuracy difference between words presented with and without diacritics ($M$=4.22) was significantly larger than the accuracy difference between sentences presented with and without diacritics ($M$=1.3), $t(98) = 5.98$, $p < .01$, effect size = 1.2. Presumably the effect of diacritics on accuracy was somewhat smaller with sentences because the additional contextual information sometimes activated the less dominant living meaning of an ambiguous word.

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 ($F < 1$).

*Summary*: The effect of diacritics was statistically smaller with sentences than with words. Nevertheless, even when they appeared in sentences, the meanings of heterophonic homographs were processed more accurately when the diacritics were presented. Conversely, the presence of diacritics had no effect on the comprehension accuracy of sentences that contained only unambiguous words. Consistent with previous research, (Abu-Liel, et al, 2014; Bourisly et al., 2013), reaction times were significantly longer when sentences contained diacritics presumably because diacritics provide additional visual information that must be processed by readers.

## General Discussion

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 we 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.

The 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. We suggest 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.

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 only occur when the experimental task requires access to a specific meaning of a heterophonic homograph.

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 et al., 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 would therefore be inappropriate to draw the conclusion that adults would read the Arabic script more effectively if it were fully vowelized. This study has instead clarified some of the consequences for skilled readers of presenting the Arabic script in a partially vowelized form.

Finally, 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.

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**Table 1.** Examples of words used in Experiment 1.

| **Living ambiguous without diacritics** | **Living ambiguous with diacritics** | **Non-living without diacritics** | **Non-living with diacritics** |
|---|---|---|---|
| السلق | السِلْق | العراء | العَرَاء |
| المدرسة | المُدَرِّسَة | الطب | الطِب |
| الحداد | الحَدَّاد | الديوان | الدِيوَان |
| المقاومة | المُقَاوِمَة | الكأس | الكَأِس |

**Table 2.** Correlations between the familiarity and availability of the meanings of ambiguous words and the accuarcy and speed of the participants on the word's first presentation.

| | 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 | -0.541 | .000 | -.224 | .164 |
| 2nd availability | -.404 | .010 | -.690, | .000 | .272 | .089 | .259 | .106 |

**Table 3.** Examples of the sentences used in Experiment 2.

| | |
|---|---|
| living ambiguous without diacritics | **ذبل السلق المقطوف** |
| living unambiguous with diacritics | أكل العجل العشب |

**Figure 1.** The effects of diacritics on the accuracy of single word comprehension.

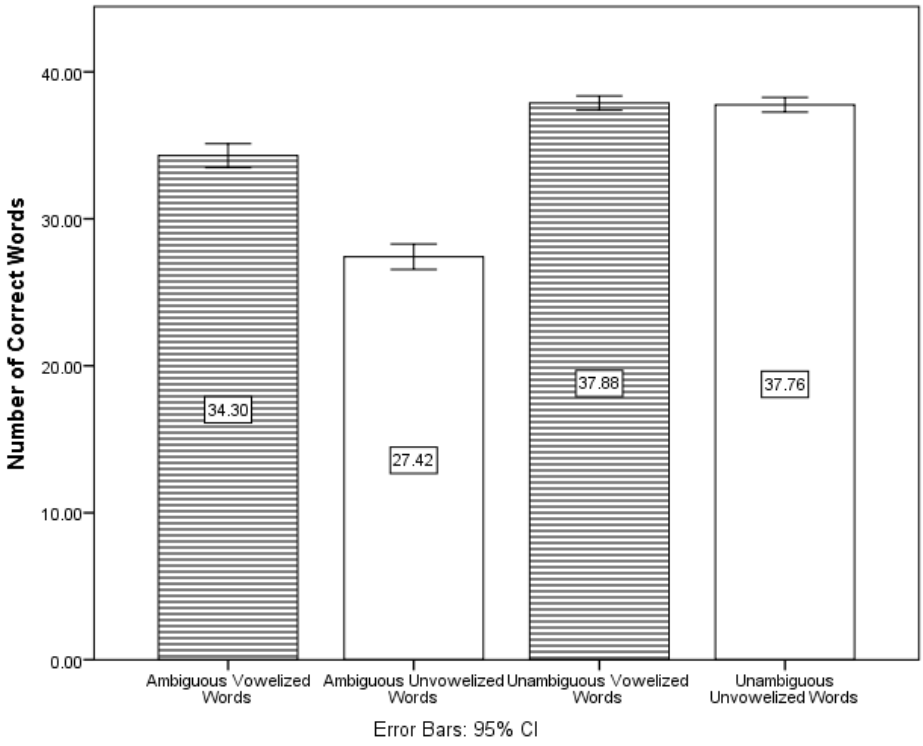

**Figure 2.** The effects of diacritics on the speed of single word comprehension.

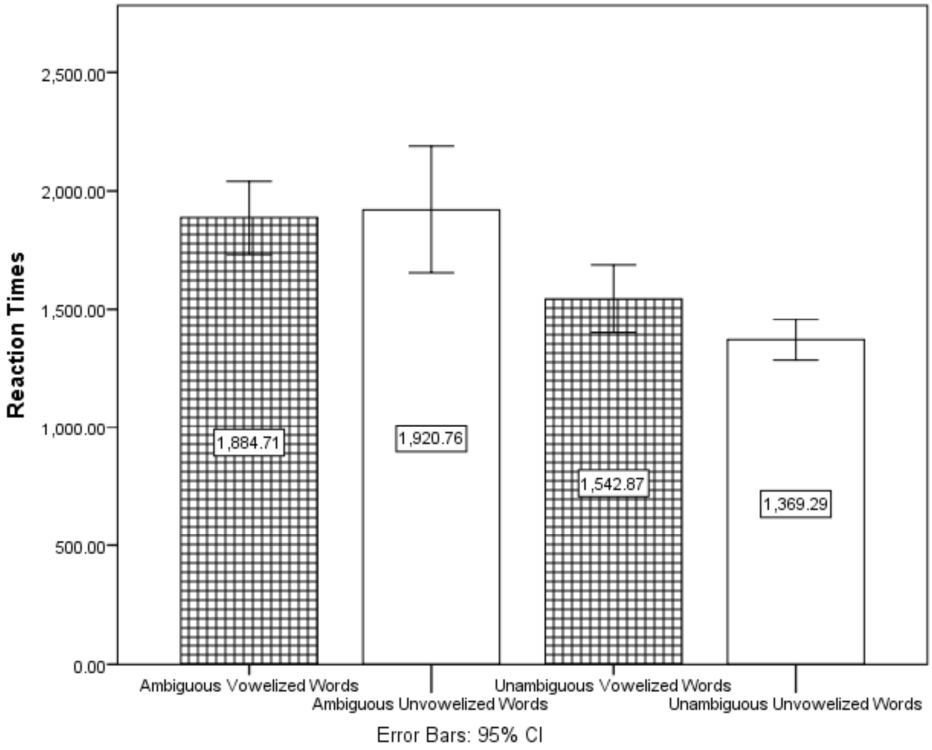

**Figure 3.** The effects of diacritics on the accuracy of sentence comprehension.

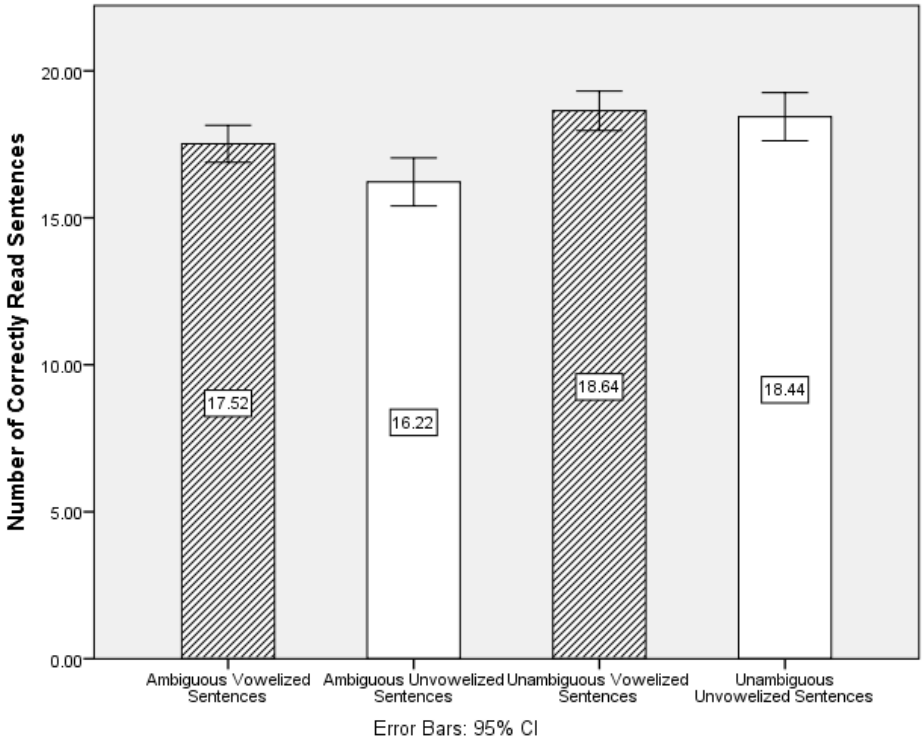

**Figure 4.** The effects of diacritics on the speed of sentence comprehension.