Revisiting the effects of interword spacing and root frequency in Arabic visual processing

Tommi Leung (leung@uaeu.ac.ae)
Department of Cognitive Sciences, United Arab Emirates University
Al Ain, United Arab Emirates

Fatima Boush (fatimaboush@gmail.com)
Department of Cognitive Sciences, United Arab Emirates University
Al Ain, United Arab Emirates

Abstract

In this study, we investigated the role of interword spacing and its interaction with Arabic root frequencies by studying readers' eye movement patterns when they read Arabic sentences. Our eye-tracking experiment results did not show any significant evidence for the interword spacing effect on Arabic word processing, which concurred with the earlier work by Leung et al. (2021). On the other hand, we replicated an earlier experiment conducted by Hermena et al. (2020) on the effect of Arabic root frequencies on word processing. Contrary to their finding, our results showed that words that differed in root frequencies significantly modulated eye movement measures. This provided further support to the status of Arabic non-concatenative roots as a morphological unit.

Keywords: Arabic; orthography; root frequency; interword spacing; roots

Introduction

The purpose of this paper is to investigate Arabic visual word processing by focusing on the effect of interword spacing (an orthographic feature) and root frequencies (a linguistic feature). Like other Latin-script languages, Arabic employs interword spacing as a spatial indicator to create word boundaries and assist readers in visual word segmentation. The studies conducted by Rayner et al. (1998) and Paterson et al. (2015) revealed that enlarging the space between words in English text led to a reduction in fixations, whereas compressing interword spaces resulted in a longer fixation. In the same vein, Mirault et al.'s (2019) study on French sentence reading revealed a decline in reading proficiency when interword spaces were eliminated. Although the importance of interword spacing is prominent in Latin-script languages, it remains uncertain whether the same phenomenon is found in Arabic, which has a distinct orthographic system. Leung et al. (2021) examined the interaction between different interword spacing conditions and eye movement measurements during Arabic sentence reading. Their experiment manipulated three interword spacing conditions, i.e., no spacing, normal spacing, and double spacing. They found that, overall, manipulating interword spacing had no significant effects on the duration of the first fixation nor total gaze duration on the target word. Although enlarging interword spaces improved sentence readability, the effect was not statistically significant. Based on these results, Leung et al. concluded that the primary purpose of including interword spacing in Arabic written text is to visually separate words, as opposed to serving other functions such as guiding saccadic movement (cf. Paterson et al., 2015).

On the other hand, the word frequency effect has been occasionally discussed in relation to the research of Arabic visual word recognition. Since Rayner and Raney's (1996) influential study, it has been widely accepted that there are distinct categorical disparities between high-frequency and low-frequency words in relation to different eye movement metrics. In Arabic, Hermena et al. (2019) and Lahoud et al. (2023) successfully reproduced the phenomenon known as the word/orthographic frequency effect. Overall, their experiments showed that high-frequency Arabic words received shorter fixation durations and had higher skipping rates than low-frequency words. To further support the claim that word frequency is de facto orthographic frequency, i.e., the frequency of the word "man" is the frequency of the occurrences of the letter "m" followed by the letter "a", which was in turn followed by the letter "t", in corpora, Hermena et al. (2017) looked into the frequency effect of the word's initial bigram by focusing on saccadic targets. Contrary to the expected word frequency effect, they found negligible modulation of saccadic programming such as saccade amplitude and initial fixation location by initial bigram frequency, a result which accorded with previous works such as Hyönä (1995) and White and Liversedge (2004, 2006). These apparently contradictory results seemed to suggest that word-level information, such as word frequency, might not entirely stem from sub lexical information such as initial bigram frequency, which led Hermena et al. to test the effect of root frequencies in Arabic word processing.

Arabic roots and root frequency

The theoretical status of morphological roots is a prominent distinctive character in Arabic/Semitic linguistics. Following McCarthy's (1981) seminal work, it has been widely accepted that many Arabic lexical words could be morphologically decomposed into roots (the meaning-defining unit formed by three to five letters which can be nonconcatenative) and patterns (a phonological template created by a sequence of vowels and consonants, which further derive the lexical/grammatical meaning of the word). In addition to the preponderance of real-language examples

In L. K. Samuelson, S. L. Frank, M. Toneva, A. Mackey, & E. Hazeltine (Eds.), *Proceedings of the 46th Annual Conference of the Cognitive Science Society.*

and theoretical arguments, there is also psycholinguistic evidence for the presence of non-concatenative roots, primarily from Hebrew (Deutsch et al., 2003; Frost et al., 1997; among others). The series of masked priming experiments conducted by (Boudelaa & Marslen-Wilson, 2001; Boudelaa et al., 2010) in Arabic were likely the initial studies that presented evidence for the presence of Arabic roots as distinct morphological units. The validity of Arabic roots was further reinforced by research on language impairment (Idrissi et al., 2008; Prunet et al., 2000) and morphological awareness (Saiegh-Haddad & Geva, 2008; Taha & Saiegh-Haddad, 2017; Tibi et al., 2019). One ensuing question about the morphological status of Arabic roots is whether the above-mentioned evidence can be further verified via other modes of experimental research, e.g., eye movement research. One immediate test, following the word frequency effect on eye movement, is on the positive evidence of the 'root frequency effect' in Arabic. 'Root frequency' is a measure of how often all grammatical words that have a common root appear in corpora (Hermena et al., 2019), analogous to the notion of word family size (Schreuder & Baayen, 1997). For instance, the root frequency of the Arabic root ك – ت - ب /k-t-b/ "write" is determined by counting the total number of word tokens derived from /ktb/, such as كتاب [kitab] "book", مكتب [maktab] "office", كاتب [katib] "writer", and so on. In the latest eye-tracking and lexical decision experiment done by Hermena et al. (2019), it was found that Arabic root frequency did not have a significant impact on the visual word identification of the target words. Their eye-movement tests did not reveal any parafoveal-on-foveal effect. In other words, the difference in Arabic root frequency did not result in a significant difference in the gaze duration of the pre-target word. Similarly, the difference between words formed by high and low root frequency did not differ significantly in the skipping rate at the target word. The outcome of the lexical decision task was somewhat intricate. There were no significant differences in response latencies when readers processed real words, regardless of whether the words had a high or low root frequency. The accuracy of the readers' answers was not affected by root frequency either. Nevertheless, they discovered a correlation between the lexicality of the target word (i.e., word vs. nonwords) and its root frequency. For actual real words, high-frequency root words resulted in greater accuracy compared to low-frequency root words, whereas the opposite was observed for nonwords.

In our current study, we replicated Leung et al. (2021) and Hermena et al.'s (2019) experiment and combined interword spacing and Arabic root frequency in a single eye movement experiment. If the conclusion of the previous studies remained tenable, the following hypotheses would be further supported: 1) There would be no interword spacing effect on word processing in terms of eye movement measures; 2) There would be no root frequency effect on word processing in terms of eye movement measures; 3) There would be no significant interaction effect between interword spacing (as an orthographic feature and Arabic root frequency (as a linguistic feature) on word processing in terms of eye movement measures.

Methods

Participants

We recruited 45 undergraduate students to participate in the study (M_{Age} = 19.6, S.D. = 1.92, Range 18-24). All participants reported being native Arabic speakers, having normal or corrected-to-normal vision and no language impairments. All received a partial course credit for their participation.

Materials & Stimuli

Table 1. Example stimuli

		Root Frequency	
		high	low
Inter-word space	regular	حرصت اللجنة على تكريم الوزير لما قدمه من جهود في خدمة الوطن	حرصت اللجنة على تكريم المؤرخ لما قدمه من جهود في خدمة الوطن
	reduced	حرصت اللجنة على تكريم الوزير لما قدمه من جه ود في خدمة الوطن	حرصت اللجنة على تكريم المؤرخ لما قدمه من ج هود في خدمة الوطن
	gloss	The committee was keen to honor the minister for the efforts he made in serving the .country	The committee was keen to honor the historian for the efforts he made in serving the .country

A list of 80 high- and low-root frequency target word-pairs was constructed in Modern Standard Arabic. Root token frequency was established using Aralex (Boudelaa & Marslen-Wilson, 2010) and raw frequencies were log-transformed to obtain standardized Zipf frequency using the formula below.

$$\text{frequency} = log_{10} \frac{root\ token\ frequency + 1}{40} + 3$$

A paired samples t-test confirmed that average root frequency was statistically significantly higher for high frequency words (M = 4.86, SD = 0.32) than for low frequency words (M = 3.32, SD = 0.22, $t(79) = 33.5$, $p < 0.001$). All words

were between five to seven letters, and pairs were matched for length. Orthographic frequency was controlled by only selecting target words with high orthographic frequency. Eighty single-line frame sentences were constructed for each word pair, maintaining a neutral context with low predictability. These sentences were rated for naturalness and predictability by a separate group of students. Comprehension questions were constructed for 25% of the sentence trials. Interword spacing was manipulated, with sentences appearing in either regular or reduced spacing using the Unicode 'Hair Space' character. an additional set of 12 sentences were constructed as practice trials.

Apparatus

Sentences were displayed in black font type set to a size of 45 pt such that all sentences occupied a single horizontally-centered line, where a single letter spanned 0.4° of visual angle. The EyeLink 1000 Plus system with a high-speed camera was used to record eye movements in head-stabilized mode. A head-and-chin reduced head movements for accurate recording.

Design

We designed a 2 x 2 mixed factorial study with interword spacing (no spacing vs. single spacing) and root frequency (high vs. low) as our experimental conditions. Participants were exposed to all levels of the two stimuli conditions. We created four Latin square counterbalanced lists of possible stimuli condition combinations such that each sentence was only read once by each participant.

Procedure

Participants gave their written consent and demographic information before sitting in an isolated room, approximately 80 cm from a monitor screen. Calibration and validation were conducted using a nine-point grid. Trials began with a central fixation screen, followed by self-paced silent reading of each sentence. Participants used the spacebar to move to the next sentence, and whenever a comprehension question was displayed, they clicked on the corresponding 'correct' or 'incorrect' images on the screen.

Results

We performed a series of linear and generalised linear mixed models to explore the results of our study. Our analysis showed that first fixation duration (FFD) and gaze durations (GD) for target words were significantly shorter for words with high frequency roots (M_{FFD} = 261 *ms*, SD_{FFD} = 5.7; M_{GD} = 271 *ms*, SD_{GD} = 12) than for words with low frequency roots (M_{FFD} = 279 *ms*, SD_{FFD} = 6.7 ; M_{GD} = 304, SD_{GD} = *12)*. However, there were no significant differences in FFD and GD across interword spacing conditions. We found a main effect of interword spacing on initial landing position (ILP), where ILP was significantly shorter for sentences with reduced interword spacing (*M* = 57.8 *px*, *SE* = 1.8) compared to regularly spaced sentences (*M* = 61.5 *px*, *SE* = 1.8).

Discussion and Conclusion

The findings from our experiment demonstrated that there was no significant interword spacing effect on Arabic word processing, yet there were notable disparities between matched Arabic words formed from high-frequency and low-frequency roots when readers mentally represented the target words within sentences. The first conclusion is consonant with the earlier study by Leung et al. (2021) who further argued that the lack of interword spacing effect might stem from the peculiar features of Arabic orthography, i.e., letters are position informative and automatically define word boundaries without the mandatory use of interword spacing. The second conclusion about Arabic root frequencies aligns with the argument made previously in support of the morphological status of Arabic non-concatenative roots (Boudelaa & Marslen-Wilson, 2001; McCarthy, 1981), yet contradicted Hermena et al.'s 2019) eye movement results. Notice that Hermena et al.'s results stemmed from two sentence reading experiments and two lexical judgment tasks. The two eye- tracking tests specifically examined the influence of orthographic and root frequency on Arabic word perception. Their findings indicated that Arabic word/orthographic frequency had an impact on word processing. Specifically, words with low frequency were associated with longer periods of fixation compared to words with high frequency. In contrast, words generated from differing root frequencies (i.e., high vs. low) did not have a significant effect on eye movement metrics. In order to conduct a more thorough examination of the potential impact of root frequency, Hermena et al. employed two additional lexical judgment tasks, utilizing the identical word stimuli employed in the preceding eye-tracking tests. Unsurprisingly, readers displayed notable variations in both the time it took them to react and their accuracy rates when reading words with high vs low word frequencies, i.e., high-frequency words elicited quicker response times and higher accuracy rates compared to low-frequency words. Additional lexical judgment tasks were conducted using words and nonwords that varied in root frequencies, resulting in more complex findings. Real word derived by high-frequency roots elicited faster response times than words formed by low-frequency roots. The scenario was inverted in the processing of nonwords. The accuracy scores for nonwords formed by low-frequency roots were significantly higher (i.e., judged as a nonword) compared to those created by high-frequency roots, which means that readers were better able to identify nonwords produced from low-frequency roots. The examination of response latency produced marginally distinct findings. No significant correlation between root frequency and reaction time was found for real words. However, a significant correlation was observed for nonwords, with nonwords formed by high-frequency roots resulting in shorter response times compared to those formed by low-frequency roots. Hermena et al. expanded upon the observed inverse relationship between words and nonwords and linked their findings to Taft's (2004) theory of morphological decomposition and especially his 'reverse base frequency

effect'. Leaving the theoretical and experimental specifics aside, Taft's lexical decision tasks demonstrated that although two words might have different word frequencies (e.g., the common word "seem" versus the less common word "mend"), these two words could still serve as the base of complex words that have comparable frequencies (e.g., the derived word "seeming" and "mending" have similar word frequencies) which did not differ in word processing. As a result, Taft suggested that the high-frequency base (in this case, "seem") potentially caused a reverse base frequency impact on the processing of the derived word (i.e., "seeming"). In other words, because the word "seeming" is used less often than its base form "seem", readers would need to exert more effort to decipher its meaning. On the other hand, since both "mend" and "mending" are low-frequency words, readers tend to pass the whole-word processing and engage in morphological decomposition (i.e., breaking down the word into its base form "mend" and the progressive suffix"-ing") and then combine these morphemes to complete the morphological process. Hermena et al. hypothesized that the lack of a root frequency effect on Arabic word processing could be attributed to the above-mentioned reverse base frequency effect. Additionally, they accurately pointed that Arabic root letters may not be spatially concatenated which further obscured visual root identification. For example, in the word كتاب [kitaab] meaning "book," the root letters ك - ت ب - are separated by the non-root letter ا. This separation further contributes to a decrease in visual saliency during lexical processing. Another potential explanation for the absence of a root frequency effect is that Arabic words are shorter than words in other European languages (Paterson et al., 2015). Consequently, readers may process a higher cognitive load when visualizing Arabic words due to the need for more extensive mental processing. This assertion was further substantiated by the observation that Arabic words were omitted to a far lesser extent compared to English words (AlJassmi et al., 2022). All these factors potentially led to the lack of a significant impact of root frequency on Arabic word processing. Our experimental findings by replicating one eye movement experiment by Hermena et al. appeared to confirm the morphological breakdown at the root level. However, the potential existence of a reverse base frequency effect requires further investigation, which we will defer to future research. If Hermena et al.'s observation that the absence of root letter concatenation hinders lexical processing is accurate, a possible avenue for future research would be to examine if the concatenation and positioning of root letters have any impact on lexical processing.

Acknowledgments

In the **initial submission**, please **do not include acknowledgements**, to preserve anonymity. In the **final submission**, **place acknowledgments** (including funding information) in a section **at the end of the paper**.

References Instructions

Follow the APA Publication Manual for citation format, both within the text and in the reference list, with the following exceptions: (a) do not cite the page numbers of any book, including chapters in edited volumes; (b) use the same format for unpublished references as for published ones. Alphabetize references by the surnames of the authors, with single author entries preceding multiple author entries. Order references by the same authors by the year of publication, with the earliest first.

Use a first level section heading, "**References**", as shown below. Use a hanging indent style, with the first line of the reference flush against the left margin and subsequent lines indented by 1/8 inch. Below are example references for a conference paper, book chapter, journal article, dissertation, book, technical report, and edited volume, respectively.

References

AlJassmi, M. A., Warrington, K. L., McGowan, V. A., White, S. J., & Paterson, K. B. (2022). Effects of word predictability on eye movements during Arabic reading. *Attention, Perception, & Psychophysics, 84*(1), 10–24.

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

Boudelaa, S., & Marslen-Wilson, W. D. (2010). Aralex: A lexical database for Modern Standard Arabic. Behavior Research Methods, 42(2), 481–487.

Boudelaa, S., Pulvermueller, F., Hauk, O., Shtyrov, Y., & Marslen-Wilson, W. (2010). Arabic morphology in the neural language system. Journal of Cognitive Neuroscience, 22(5), 998–1010.

Deutsch, A., Frost, R., Pelleg, S., Pollatsek, A., & Rayner, K. (2003). Early morphological effects in reading: Evidence from parafoveal preview benefit in Hebrew. Psychonomic Bulletin & Review, 10(2), 415–422.

Frost, R., Forster, K., & Deutsch, A. (1997). What can we learn from the morphology of Hebrew? A masked-priming investigation of morphological representation. Journal of Experimental Psychology-Learning Memory And Cognition, 23(4), 829–856.

Hermena, E. W., Liversedge, S. P., Bouamama, S., & Drieghe, D. (2019). Orthographic and root frequency effects in Arabic: Evidence from eye movements and lexical decision. Journal of Experimental Psychology-Learning Memory And Cognition, 45(5), 934–954.

Hermena, E. W., Liversedge, S. P., & Drieghe, D. (2017). The influence of a word's number of letters, spatial extent, and initial bigram characteristics on eye movement control during reading: Evidence from Arabic. Journal of Experimental Psychology: Learning, Memory, and Cognition, 43(3), 451–471.

Hyönä, J. (1995). Do irregular letter combinations attract readers' attention? Evidence from fixation locations in words. Journal of Experimental Psychology: Human Perception and Performance, 21(1), 68–81.

Idrissi, A., Prunet, J.-F., & Béland, R. (2008). On the mental representation of Arabic roots. Linguistic Inquiry, 39(2), 221–259.
Lahoud, H., Eviatar, Z., & Kreiner, H. (2023). Eyemovement patterns in skilled Arabic readers: Effects of specific features of Arabic versus universal factors. Reading and Writing.
Leung, T., Boush, F., Chen, Q., & Al Kaabi, M. (2021). Eye movements when reading spaced and unspaced texts in Arabic. Proccedings of the Annual Meeting of the Cognitive Science Society, 43.
McCarthy, J. J. (1981). A prosodic theory of nonconcatenative morphology. Linguistic Inquiry, 12(3), 373–418.
Mirault, J., Snell, J., & Grainger, J. (2019). Reading without spaces revisited: The role of word identification and sentence-level constraints. Acta Psychologica, 195, 22–29.
Paterson, K. B., Almabruk, A. A. A., McGowan, V. A., White, S. J., & Jordan, T. R. (2015). Effects of word length on eye movement control: The evidence from Arabic. Psychonomic Bulletin & Review, 22(5), 1443–1450.
Prunet, J.-F., Béland, R., & Idrissi, A. (2000). The mental representation of Semitic words. Linguistic Inquiry, 31(4), 609–648.
Rayner, K., Fischer, M., & Pollatsek, A. (1998). Unspaced text interferes with both word identification and eye movement control. Vision Research, 38(8), 1129–1144.
Rayner, K., & Raney, G. E. (1996). Eye movement control in reading and visual search: Effects of word frequency. Psychonomic Bulletin & Review, 3(2), 245–248.
Saiegh-Haddad, E., & Geva, E. (2008). Morphological awareness, phonological awareness, and reading in English Arabic bilingual children. Reading and Writing, 21(5), 481–504.
Schreuder, R., & Baayen, R. H. (1997). How complex simplex words can be. Journal of Memory and Language, 37(1), 118–139.
Taft, M. (2004). Morphological decomposition and the reverse base frequency effect. Quarterly Journal Of Experimental Psychology, 57(4), 745–765.
Taha, H., & Saiegh-Haddad, E. (2017). Morphology and Spelling in Arabic: Development and Interface. Journal of Psycholinguistic Research, 46(1), 27–38.
Tibi, S., Tock, J. L., & Kirby, J. R. (2019). The development of a measure of root awareness to account for reading performance in the Arabic language: A development and validation study. Applied Psycholinguistics, 40(2), 303–322.
White, S. J., & Liversedge, S. P. (2006). Linguistic and nonlinguistic influences on the eyes' landing positions during reading. Quarterly Journal of Experimental Psychology, 59(4), 760–782.
White, S., & Liversedge, S. (2004). Orthographic familiarity influences initial eye fixation positions in reading. European Journal of Cognitive Psychology, 16(1–2), 52–78.