Reading text with and without diacritics alters brain activation: The case of Arabic

Abstract

Diacritics in Arabic are optional orthographic symbols used to alter the pronunciation of a letter or distinguish between words of similar spellings, which may add or subtract complexity by imposing additional loads on the individual's information-processing system. In this study, we explored how reading Arabic text with and without diacritical signs (known as ḥarakāt) can influence readers' brain activation. An electroencephalogram (EEG) recording of 18 subjects was used in this study to assess the differences in brain activation while reading in two reading conditions (with and without ḥarakāt). The results showed that ḥarakāt had a significant impact on the cognitive responses of subjects as exemplified by differences in cortical activity between the conditions. Our results imply promising results in the application of reading skills where diacritical marks may play a key role in increasing the level of attention an individual pays to text, thus improving information-processing accuracy.

Keywords: diacritics, Arabic text, reading skills, information-processing accuracy

Introduction

Reading is a typical practice in our daily life that helps us create meaning for communication and learning purposes (Al-Samarraie, Sarsam, & Umar, 2017). In linguistics, the process of reading is commonly thought to be driven by the syntactic characteristics of reading material, along with other morphological and narrative characteristics (Snow, 2002; Tracey & Morrow, 2017).

Arabic writing is cursive and complex in its nature. It is a consistent letter-sound alphabetical system with 28 letters in which words are separated by spaces. The structure of Arabic words is based on trilateral (three-letter) roots, where some word combinations are typically shaped by the use of affixes and vowels. Readers may treat some of these combinations as the same, particularly when they are written without vowels. Therefore, reading texts without vowels may result in different meanings and thus different understanding of the words (Ryan & Meara, 1992). This is because diacritics in Arabic add vowel information omitted in unvoweled texts, which may add or subtract complexity by imposing additional loads on information processing.

Arabic orthography when dealing with similar graphemes and different graphemes have been extensively discussed in the work of Buckwalter (2004); and Ibrahim, Eviatar, and Aharon-Peretz (2002) who argued that the complexity imposed by the use of different marks (diacritics) could potentially influence readers' visual recognition of words. This has led many scholars to deeply investigate and examine the effects of using different Arabic structures on readers' cognitive responses, and their potential for improving reading skills (Crossley, Skalicky, Dascalu, McNamara, & Kyle, 2017), increasing comprehension (Primor, Pierce, & Katzir, 2011), and reducing reading errors (Natour, Darawsheh, Sartawi, Marie, & Efthymiou, 2016; Schimmel & Ness, 2017). However, most previous efforts have not truly justified the role of these characteristics in stimulating brain activation while reading under different conditions. For instance, most previous studies on Arabic language processing (e.g.,Ibrahim et al., 2002; Maroun & Hanley, 2017; Taouka & Coltheart, 2004) have employed priming paradigms where discrete-trial reaction-time of context effects were commonly used to understand better how individuals read, which provide a limited understanding of individual cognitive processing in these areas. The absence of using biofeedback measures through neurological and physiological reactions in the above studies of Arabic orthography may offer limited insights into the development of a general theory of reading, especially when no attempt has been made to examine individual brain activity differences corresponding to the reading of Arabic text with and without diacritics.

On the other hand, some previous studies (e.g., Abu-Rabia, 2001; Maroun & Hanley, 2017) have attempted to determine potential facilitators that allow readers to process text efficiently, which include reducing the use of different symbols as diacritical marks, or simply diacritics (known as harakāt). Still, the use of diacritics is optional in Arabic, and readers must rely on grammar to distinguish and pronounce words when reading text without diacritics (Aabed, Awaideh, Elshafei, & Gutub, 2007; Maroun & Hanley, 2017). According to Azzam (1989), correct reading of the Arabic language involves more than alertness, concentration and knowledge of the grammar. One possible example comes from Sniezek and Buckley (1995), who described the role of cueing in promoting individual judgement by increasing accuracy and reducing uncertainty. Other scholars, such as Cosman and Vecera (2011); and Metzner, Malsburg, Vasishth and Rösler (2017), have also referred to the role of some reading conditions in allowing for and encouraging more consideration of alternative meanings than other conditions. However, due to the lack of evidence about the true impact of Arabic diacritics on readers, this study examined how the use of diacritics (specifically, harakāt) may influence individuals' brain activation when reading Arabic text.

Based on these, this study was conducted to answer 'How reading text with and without diacritics influence the brain activity of Arabic readers?' This question was answered by recording the brain activity of 18 subjects while reading Arabic texts under two conditions (with and without ḥarakāt). We assumed that diacritics in text may affect the cognitive abilities of individuals to improve Arabic text reading accuracy. Findings from this study might offer some valuable insights into the impact of diacritics on individuals' information processing abilities.

Diacritics in the Arabic language

The Arabic language is the main mean of communication for many people around the world. However, a limited amount of research has examined the cognitive processes that are involved in reading Arabic text. Previous studies in information science and reading have identified the role of diacritical signs in facilitating the reading, processing, and understanding of text (e.g., Abadzi & Martelli, 2014; Abu-Rabia, 1997; Maroun & Hanley, 2017; Salehuddin & Winskel, 2014). They suggested different models for characterizing the effect of diacritics and contexts for facilitating the recognition of Arabic words with regards to various reading conditions.

Abu-Rabia (2007) stated that readers usually rely on the triliteral/quadriliteral roots of words for initial lexical access, which aids their reading accuracy. However, diacritics may still facilitate word recognition regardless of the writing style (narrative, informative, poetic, or Koranic). This, however, could be attributed to readers' awareness of diacritics, so that their reading accuracy is maintained under any conditions (Mickan, 2017). Landi and Ryherd (2017) stated that readers' awareness of text structure plays a key role in defining morphologically complex words. This led the authors to assume that readers' awareness of text structure can be affected by the nature of morphological relations, which, as explained by Bishara and Weiss (2017), correlate with the accuracy and speed of reading words. As such, it can be argued that reading Arabic text with diacritics may influence readers' reading performance. In other words, readers may read a text without diacritics correctly, using their prior knowledge of text content, but their schemata are not necessarily activated while reading.

Other studies (Layes, Lalonde, & Rebaï, 2017; Maroun & Hanley, 2016; Taha, 2016) have shown that readers' awareness of Arabic diacritics can potentially influence their reading performance. In a study by Hyönä and Vainio (2001), a remarkable processing pattern (eye fixation) was observed in which a clause construction was marked by less perceivable bound morphemes. They found that it is more difficult to process text when the same construction is denoted by a visually distinct free morpheme. This was reasoned to occur because both structural complexity and structural frequency may influence the ease with which linguistic expressions are processed during reading. Abdelhadi, Ibrahim, and Eviatar (2011), on the other hand, found no impact of orthographic factors (such as morphology and spelling) on reading accuracy and comprehension, which may have been because the individuals had prior knowledge of these factors. Hermena, Drieghe, Hellmuth, and Liversedge (2015) observed the perceptual behavior of readers when reading fully diacritized sentences, and their results showed small effects. This was related to the increase in visual crowding, which led to the low processing of diacritics when performing the reading task. Maroun and Hanley (2016) found that diacritics significantly increased individuals' semantic decisions about ambiguous words as compared to unambiguous words. In this study, it was assumed that the use of diacritics in Arabic can influence the way individuals process and understand text. In addition, our review of the literature showed limited evidence of the impact of Arabic diacritics on readers' brain activity, and thus the motivation for this study.

Method

Subjects

A total of 18 participants (14 male and 4 female) were recruited in this experiment. They were recruited from a university student population (undertaking higher education) in exchange for course credit. Their ages ranged between 26 to 31 years (mean = 28, SD = 0.03). All participants had normal or corrected-to-normal vision and were right-handed, with no diagnosed learning disabilities or neurological or hearing problems (according to self-report). The participants were all bilingual (attending courses taught with English and Arabic) native Arabic speakers, whose Arabic language ability was fully developed. All of them read Arabic (their first language) books and online Arabic newspapers almost on a daily basis (these adult students were considered proficient in Arabic). Students who reported that they read in Arabic occasionally (their reading in Arabic was not on a daily basis) were excluded from the study. Despite the fact that Arabic diacritics is taught from early grades of primary schools (especially in Arabic and Islamic subjects), we asked all the participants to confirm their familiarity with the use of diacritics in reading and writing. All the participants were familiar with the use of Arabic diacritics, thus making them suitable for the purpose of this study.

Students' Arabic reading skills was determined on the basis of their scores on an Arabic reading test to ensure that they could adequately read Arabic. The initial reading test comprised a paragraph (270 Arabic words with diacritics) from the Ghayat Al-Hayât by May Ziade (different from the one used in the main study), and the ability to read was assessed by measuring the time needed to finish reading the paragraph along with the number of mistakes made by the participant. Results showed no significant differences in students' Arabic reading performance.

This research complied with the American psychological association code of ethics where informed consent was obtained from each participant.

Reading materials

Reading materials were obtained from Ghayat Al-Hayât, written by May Ziade. Two reading conditions were created on the same paragraph (one with ḥarakāt and one without ḥarakāt). Stimuli were displayed using PowerPoint, and the context of the two reading conditions was written in classical Arabic (al-fuṣḥá). Arial font type, black color, and 24-point size were used in both conditions. Three Arabic language experts were asked to review and assess the suitability of using diacritics in the reading stimuli. Precisely, the experts' role was to ensure that the use of ḥarakāt was properly placed on each word, and that the meaning of each word can be correctly described in terms of these diacritics. After that, a finalized version of reading text was used. An example of the reading materials for both conditions is presented in Figure 1.

Ḥarakāt

مَوْضُوعُنَا الْيَوْمُ ،"غَايَةُ الْحَيَاةِ"، وَلَا أَعرفُ كلمةً خَطِيرَةً كَهَذِهِ وَأَكْثَرٌ تفلتًا مِنْ حُدودِ
التَّعْرِيفِ، إِنَّ لَفْظَةَ مَعنَاهَا التامّ تَشْمَلُ الْكَوْنَ بِأَسْرِهِ مِمَّا يُرى وَمَا لَا يُرى، وَهِيَ ذَلِكَ
التيَّارُ الْخَفِيُّ النَّافِذُ فِي كَلِّ شَيْءٍ، الْمُحِيطُ بِكُلِّ كَائِنٍ، وَقَدْ حَوَى مِنَ الْاِقْتِدارِ وَالْجَبَرُوتِ
مَا أَلْقَى فِي رُوعِنَا أَنَّه مِنْ رَوْحِ الله، كَأَنَّنَا نَحْسَبَ الْحَيَاةَ نَسَمَاتُ نُورٍوَإِنْعاشٍ مُنْطَلَقَةً مِنْ
صَدْرِتِلْكَ الْقُوَّةِ الْكُبْرَى الَّتِي نَسَبحَ جَمِيعاً فِي بِحارِجُودِهَا، وَنُسَمِّيهَا:" اللهُ ". فَإِذَا شمِلَ
مُعنّى الْحَيَاةِ جَمِيعَ الْمَوْجُودَاتِ فَأَنَّى لَنَا تَعْيِينُ غَايَتِهَا؟ مِنْ ذَا الَّذِي يَجْرُؤُ عَلَى تَعْيِينِ
غَايَةِ الْفَلَكِ فِي دَوْرَتِهِ، وَالنُّجُومِ فِي سَيْرِهَا، وَالْمُذْنِبَاتِ فِي تَكَوُّنِهَا، وَالشَّمُوسِ فِي
تَشَعُّعِهَا وَاِحْتِراقِهَا، وَالنَّيَازِكِ فِي تَسَاقُطِهَا عَلَى الأرض حجارًا سَوْداءَ؟ مِنْ ذَا الَّذِي.......

Non-ḥarakāt

موضوعنا اليوم ،"غاية الحياة"، ولا أعرف كلمة خطيرة كهذه وأكثر تفلتا من حدود
التعريف، إن لفظة معناها التام تشمل الكون بأسره مما يرى وما لا يرى، وهي ذلك
التيار الخفي النافذ في كل شيء، المحيط بكل كائن، وقد حوى من الاقتدار والجبروت
ما ألقى في روعنا أنه من روح الله، كأننا نحسب الحياة نسمات نوروإنعاش منطلقة من
صدر تلك القوة الكبرى التي نسبح جميعا في بحار جودها، ونسميها:" الله ". فإذا شمل
معنى الحياة جميع الموجودات فأنى لنا تعيين غايتها؟ من ذا الذي يجرؤ على تعيين
غاية الفلك في دورته، والنجوم في سيرها، والمذنبات في تكونها، والشموس في
تشععها واحتراقها، والنيازك في تساقطها على الأرض حجارا سوداء؟ من ذا الذي ....

Figure 1: Reading materials

Procedure

We first provided the participants a brief description about the purpose of the study and their role in it after screening. To provide a comfortable reading environment to the participants, the environment was silent and the lights in the lab were dimmed. Prior to the reading session, all participants were instructed to read each of the two types of text.

While reading, participants were fitted with the EEG sensors and subsequently data quality tests were run. The passages in both reading scenarios were displayed in PowerPoint using a Lenovo computer. During the first trail, participants read the passage with ḥarakāt. After two weeks break, participants read the same text passage without ḥarakāt. This interval period seemed to be enough to control for learning effect, which is consistent with previous research on reading (e.g., Alptekin, & Erçetin, 2010; Jensen, & Vinther, 2003). Also, in order to ensure that the order of the reading conditions was counter-balanced across participants,

participants were randomly assigned to one treatment for the first trial (either ḥarakāt text" or "non- ḥarakāt text) and received the alternative for the second trial.

Data for each participant was retrieved and labelled for analysis purposes. Time was not limited in the two reading conditions. The reading accuracy of each participant was assessed by two Arabic lecturers. We recorded participants reading the two texts for experts to review and assess the accuracy. The assessment of participant reading accuracy was achieved by considering all ḥarakāt within the diacritically-marked text and all the ḥarakāt absent from the non-diacritics text. We allowed participants to pronounce the ḥarakāt of the last consonant in a word in any acceptable way in Arabic, while missing ḥarakāts for other letters had to be pronounced accurately.

Rationale for using EEG

Recent studies on information processing and cognitive development have shown the potential of using various physiological measures such as heart rate variability (e.g., McDuff et al., 2014)) and eye movement (e.g., Sarsam and Al-Samarraie, 2018) in estimating cognitive or affective states of individuals of various ability levels. The literature also showed the role of other physiological techniques, such as Positron Emission Tomography (PET) and EEG, in measuring brain activity for a range of cognitive processes. EEG is a popular neuroimaging technique used to analyze electrical activity produced by the brain via electrodes that are placed on the scalp of the subject (Anderson et al., 2011). EEG also provides an easy and a low cost experimental setup as compared to other techniques (such as Functional magnetic resonance imaging (fMRI), brain positron emission tomography (PET), and magnetoencephalography (MEG) (Chi, Jung, & Cauwenberghs, 2010; Guermandi, Cardu, Scarselli, & Guerrieri, 2014; Xu et al., 2011). The reliability and validity of using the EEG have been reported in many previous studies, showing that the EEG was sensitive enough to differentiate cognitive load with high precision (Al-Samarraie, Eldenfria, Price, Zaqout, & Fauzy, 2019; Al-Samarraie, Eldenfria, Zaqout, & Price, 2019; Murata, 2005). Thus, in the current study, we used EEG to investigate the brain activity of participants when reading Arabic text with and without diacritics.

EEG recording and pre-processing

The Emotiv Epoc device was used to record EEG data at 128 Hz. It consists of 14 channels (AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, AF4) with 2 reference channels placed according to the international 10–20 system. The type of electrodes used in this study were wet. The reference and ground electrodes used for common mode rejection were positioned between P3 and P4. The recorded signals from the 14 channels were high-pass filtered with a 0.16 Hz cut-off, pre-amplified and low-pass filtered at an 83 Hz cut-off. Then, the processed signals were digitized at 2048 Hz. The digitized signal was filtered using a 5th-order sinc notch filter (50–60 Hz), low-pass filtered and down-sampled to 128 Hz. Before reading, a 15-sec baseline was recorded with participants looking at a white screen. In addition, an Epoch was chosen to allow us to observe changes in readers' brain activity while reading in the two conditions. Electrooculogram (EOG) was also recorded, and later used to identify blink artifacts from the recorded EEG data. We used the EEGLAB's topographical map to locate the EOG /blinking artefact (and other artefacts). The location of all the electrodes (including EOG-related electrodes) was obtained from the Emotiv Epoc database uploaded into the EEGLAB toolbox.

For offline analysis, we first utilized a high-pass filter at 1 Hz to remove baseline drift. A notch filter was used at 50 Hz and 60 Hz for attenuating line noise. Subsequently, bad electrodes were identified and removed. Then, EEG signals were re-referenced to common-average reference. We used independent components analysis (ICA) decomposition in

EEGLAB to remove stereotypical artefacts (blinking and lateral eye movement) (see Figure 2 for more details).

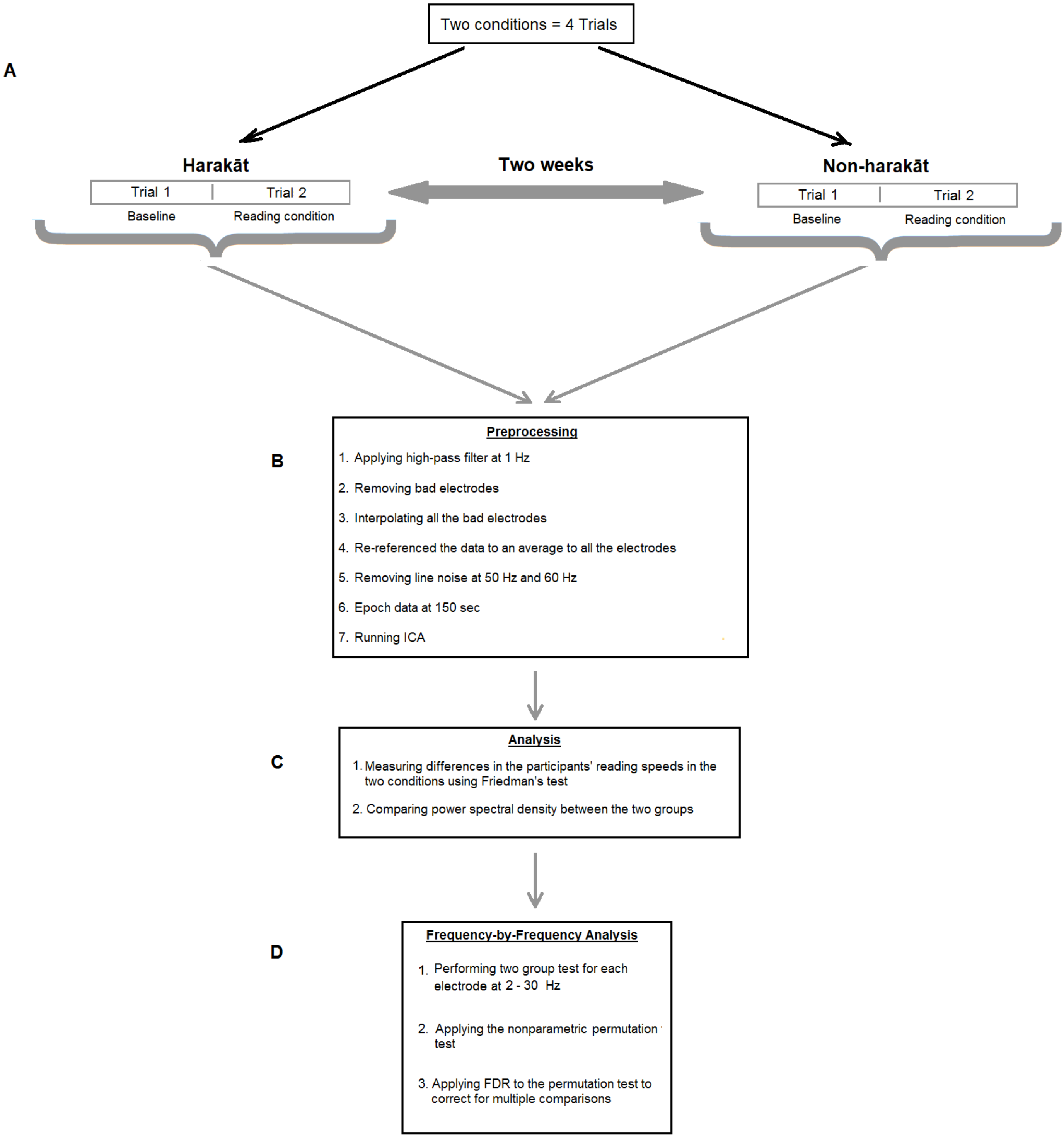

Figure 2: EEG experiment

The power spectral analysis was used to provide a deeper view of participants' brain activation using a nonparametric permutation test applied to each band power spectra of subjects within each electrode. The false discovery rate (FDR) method was used to control the detection of false positives in a way that was not biased in favour of any particular method (Henriques et al., 2014; Lage-Castellanos, Martínez-Montes, Hernández-Cabrera, & Galán, 2010). A nonparametric Friedman test was then used to determine whether changes in brain activation were statistically significant.

Results

As shown in Figure 3, the results showed that participants' reading accuracy was significantly better for text with ḥarakāt than text without ḥarakāt. Participants spent more time reading text with ḥarakāt (*M* = 1088.48, *SD* = 6433.34) than without ḥarakāt (*M* = 890.22, *SD* = 658.25). However, reading accuracy varied across the two scenarios; participant reading accuracy of text with ḥarakāt was higher (89%) than it was without ḥarakāt (77%).

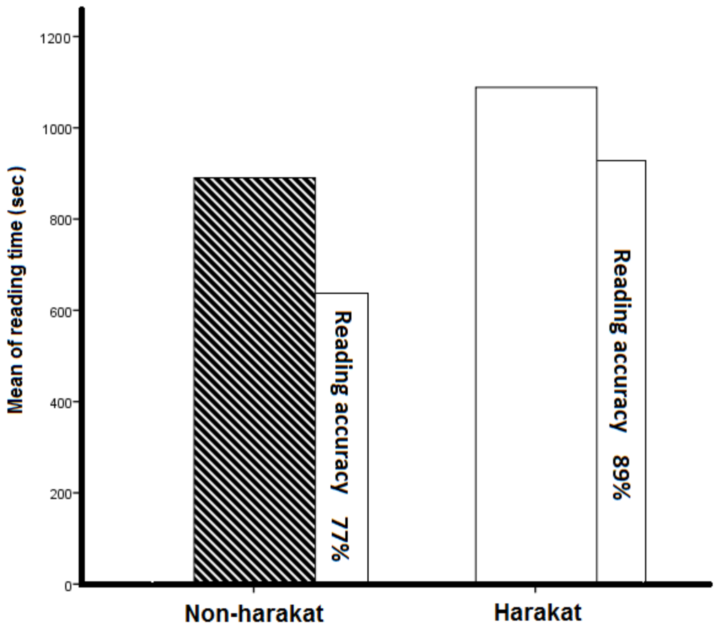

Figure 3: Reading time and accuracy for ḥarakāt and non-ḥarakāt scenarios

To better understand the influence of ḥarakāt and non-ḥarakāt on participant reading, we examined the differences in participant brain activation based on the data for four bands (Delta, Theta, Alpha, and Beta). Table 1 shows the frequency bands in each electrode for ḥarakāt and non-ḥarakāt scenarios.

Time-frequency analysis performed on the EEG data during the reading of text with and without diacritics showed that oscillatory dynamics (considered to be responsible for the interplay of brain regions for cognitive control in memory and learning (Buzsáki & Draguhn, 2004)) were significantly different between the two conditions in the 2-4 Hz (lower Delta) frequency range. Over frontal electrodes, we observed a significant beta band power decrease starting as early as 1.8 s when reading text with diacritics condition. In the reading of text without diacritics, a Delta power increase was observed during this time interval. A significant reduction in the delta frequency when reading text with ḥarakāt compared to reading non-ḥarakāt text was obtained. The Delta band results yielded a significant correlation and difference between the sub-bands of T7, P7, and AF4 when reading text in both conditions ($t18 = -2.32$, $p < 0.01$ [ḥarakāt: mean = 37.84, SD = 3.92; non-ḥarakāt: mean = 39.1, SD = 2.80]).

With respect to the Theta band, the results yielded a significant correlation and difference between the sub-bands of T7, F4, and O7 when reading text in both conditions ($t18 = -2.11$, $p < 0.01$ [ḥarakāt: mean = 33.80, SD = 4.10; non-ḥarakāt: mean = 38.69, SD = 2.35]). We found that the Theta levels of participants reading the text with ḥarakāt were lower than those for participants reading the text without ḥarakāt.

We also found a significant correlation and difference in Alpha channels F4, FC5, T7, P7, and T8 ($t18 = -3.37$, $p < 0.01$ [ḥarakāt: mean = 34.25, SD = 5.85; non-ḥarakāt: mean = 39.33, SD = 4.11]). Our assessment of the Alpha frequencies revealed that participants required lower memory capacity when reading non-ḥarakāt text than when reading ḥarakāt text, this contributing to the cortical activation and increased activity in left prefrontal cortex.

Significant correlation and difference in participant Beta channels F4, FC6, FC5, P7, T7, and O1 ($t18 = -3.89$, $p < 0.01$ [ḥarakāt: mean = 26.88, SD = 2.86; non-ḥarakāt: mean = 32.75, SD = 3.49]) was found. The Beta range (13 to 30 Hz) decreases in amplitude with increasing load when reading text with diacritics.

Table 1: Frequency bands in each electrode for ḥarakāt and non-ḥarakāt scenarios

Frequency bands	**Condition**	**Electrode**	**M** (µV^2/Hz)	**SD** (µV^2/Hz)	t *(p)*
Delta	Ḥarakāt	AF4	37.95	3.97	−2.32 *(p < 0.01)*
		T7	36.46	3.67	
		P7	39.10	4.12	
	Non-ḥarakāt	AF4	36.03	4.85	
		T7	40.25	1.89	
		P7	41.02	1.67	
Theta	Ḥarakāt	F4	33.49	2.17	−2.11 *(p < 0.01)*
		T7	33.33	3.60	
		O1	34.57	6.54	
	Non-ḥarakāt	F4	37.69	2.50	
		T7	39.33	2.81	
		O1	39.06	1.73	
Alpha	Ḥarakāt	F4	32.13	3.15	−3.37 *(p < 0.01)*
		T8	37.14	6.05	
		FC5	31.56	7.21	
		T7	33.56	6.44	
		P7	36.86	6.41	
	Non-ḥarakāt	F4	37.71	4.09	
		T8	41.33	3.55	
		FC5	37.29	5.39	
		T7	39.60	3.38	
		P7	40.71	4.12	
Beta	Ḥarakāt	F4	27.28	1.41	−3.89 *(p < 0.01)*
		FC6	23.98	2.39	
		FC5	24.64	2.77	
		T7	27.50	3.07	
		P7	30.59	3.07	
		O1	27.28	4.43	
	Non-ḥarakāt	F4	31.39	2.45	
		FC6	30.30	2.18	
		FC5	30.74	6.96	
		T7	35.41	4.11	
		P7	35.73	2.29	
		O1	32.90	2.96	

Reader brain activation in the Delta, Theta, Alpha, and Beta bands is illustrated in Figure 4 below, showing significant differences ($p < 0.01$) in all correlated channels. Reading with ḥarakāt was found to increase the focused attention of readers to the text (based on the shared reading of T7 and P7 channels in most bands). In addition, the enhanced involvement of both right and left hemispheres during text reading may relate to the role of ḥarakāt in developing the intellectual ability of readers to process information.

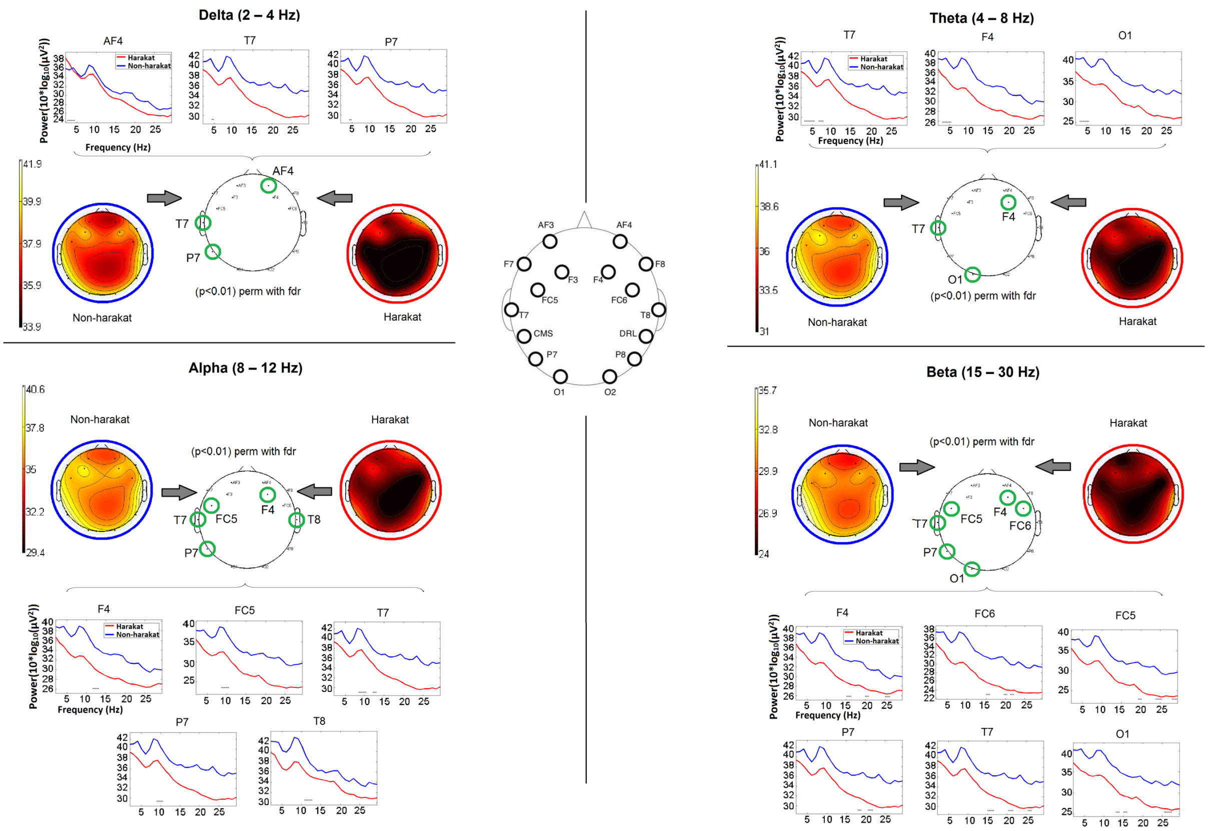

Figure 4: Comparison of brain activation while reading text with and without ḥarakāt

Discussion

The potential influence of diacritics on readers' brain activation response was explored in this study. The results showed that the use of diacritical signs when reading Arabic text had a marked impact on the reading accuracy of participants, as compared to the non-ḥarakāt scenario. This was evident from the results of reading accuracy, which is inline with previous works on reading, particularly those of Abu-Rabia (1997), who investigated the effects of vowels on the reading accuracy of readers.

The examination of readers' brain activation in ḥarakāt and non-ḥarakāt scenarios showed that diacritics in Arabic text promotes the brain activity of readers by increasing attention levels, thus reducing reading errors. Because of the limited evidence about the effect of diacritics on the cognitive functioning and/or overall brain activation of readers, this study found that the use of harakāt in Arabic texts may significantly increase readers' motor responses with some proportion of error-specific processing (Cavanagh et al., 2012). Based on the views of Zarjam, Epps, and Chen (2011) on the role of Delta frequency sub-bands in characterizing the working memory load of individuals while processing the message in a text, it can be said that reading with ḥarakāt has promoted participants' understanding of the message (as indicated by the decrease in Delta frequency band).

Since the cognitive skills required for an individual to complete a certain task is essential for processing contextual stimuli, this decreases with practice and when activity requires higher attentional demands (Rippon & Brunswick, 1998). In light of this, it can be anticipated that reading with diacritics may help promote cognitive skills by reducing errors while processing the text. Such skills can be effectively applied when processing other aspects of life (as indicated by the decrease in Theta frequency band).

Our results also support the claim made by Maroun and Hanley (2017) that diacritics can be used in Arabic language to improve the comprehension of heterophonic homographs by facilitating access to semantic representations. This is evident from the Beta frequency band which decreases for difficult tasks relative to the easy tasks (Gevins et al., 1998). The results also support the finding of Elsayyad, Everatt, Mortimore, and Haynes (2017) that working memory performance is associated with Arabic reading comprehension regardless of the form of script (vowelized versus non-vowelized). Based on this, it is assumed that readers' awareness of ḥarakāt might be significantly related to their reading accuracy in which diacritical marks enabled readers to sufficiently recognize and correctly interpret complex words.

Our result is of major importance to information-processing research on how diacritics facilitate word recognition. It also enriches the previous efforts of Taouka and Coltheart (2004) and Hamed and Zesch (2017), who have questioned the cognitive consequences involved in learning to read Arabic texts, and how diacritics can be used to reduce errors and indicate the meanings of words. Our finding also supports the notation by Ibrahim (2013), who found significant differences between vowelized and unvowelized word naming. Furthermore, reading text with diacritics had a significant effect on the level of attention paid by readers, which enrich previous work by Abu-Rabia (2001) on the role of vowels in Arabic reading. In addition, the level of attention an individual pays to the text can be increased with such modes of reading, thus improving information-processing accuracy. We also think that individual visual working memory when reading text with diacritics would serve to reduce uncertainty by prioritizing memory-matching items rather than gemination (consonant doubling or extra length). The is supported by Miller (2004) who reported that adding vowel diacritics can facilitate individuals' quantitative and qualitative short-term memory performance.

Theoretical and practical implications

The normalized activation of the 18 subjects showed that text settings have a great impact on the cognitive functioning of individuals, and may correspond to the focused attention, sufficient recognition, and comprehension of the text. Our experiment provided an in-depth justification of the cognitive consequences related to how the insertion of diacritics into Arabic text can significantly alter the ability of a reader to process and understand the text. This adds to the work of Ashby, Treiman, Kessler and Rayner (2006) in that certain diacritical mark features may increase the possibility of readers being able to encode vowel phonemes. Our findings with regard to the impact of diacritical sings on the cognitive responses of Arabic speakers have some implications for the acquisition of reading in Arabic and may offer a way to enhance reading development, such as preventing reading difficulties in adults (Saigh, & Schmitt, 2012), facilitating the acquisition of reading skills (Gough, Hoover, Peterson, Cornoldi, & Oakhill, 1996), and increasing second language reading performance (Randall, 2009).

This study also provides a number of implications to current information processing and reading theories (e.g., Atkinson & Shiffrin, 1968; Baddeley, 1992, 2003; Just & Carpenter, 1992) with regards to the existence of an intrinsic link between readers' brain activation accuracy and the use of diacritical signs. For example, it suggests that diacritical signs may potentially promote the selective processing of individuals to focus attention on information that would otherwise decay, thus resolving decoding ambiguity. In addition, changes in total capacity due to processing diacritical signs may potentially affect the execution of a wide range of processes in a wide range of tasks. This study also provides an important new perspective to complement the development of phonological recognition systems for Arabic language through which diacritical signs can be used to accurately identify the exact word meaning. The obtained results enrich the current understanding on how diacritical signs may play a central role in Arabic decoding because grapheme-phoneme relations are very complex in Arabic, thus leading to the belief that functions of diacritics may contribute to the individual's reading development needs (Leil, Share, & Ibrahim, 2014).

Limitation and future works

This study was limited to native Arabic speakers with typically good reading profiles. In addition, the particular effects of ḥarakāt were examined in this study. Therefore, future studies may consider examining the effect of other diacritical elements on the reading of Arabic texts. The examination of reader brain activation for different reading profiles and contexts can be further investigated, to determine the cognitive antecedents that contribute to overall reading accuracy.

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