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Vowelling and semantic priming effects in Arabic

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ABSTRACT

In the present experiment we used a semantic judgment task with Arabic words to determine whether semantic priming effects are found in the Arabic language. Moreover, we took advantage of the specificity of the Arabic orthographic system, which is characterized by a shallow (i.e., vowelless words) and a deep orthography (i.e., vowelless words), to examine the relationship between orthographic and semantic processing. Results showed faster Reaction Times (RTs) for semantically related than unrelated words with no difference between vowelless and vowelless words. By contrast, Event Related Potentials (ERPs) revealed larger N1 and N2 components to vowelless words than vowelless words suggesting that visual-orthographic complexity taxes the early word processing stages. Moreover, semantically unrelated Arabic words elicited larger N400 components than related words thereby demonstrating N400 effects in Arabic. Finally, the Arabic N400 effect was not influenced by orthographic depth. The implications of these results for understanding the processing of orthographic, semantic, and morphological structures in Modern Standard Arabic are discussed.

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1. Introduction

The process of written word identification is thought to bring into play at least three domains of knowledge: (a) orthographic knowledge which allows the computation of graphemes and their position in the word, (b) phonological knowledge which supports the computation of sounds from graphemes, and (c) semantic knowledge which provides information about the meaning of words (Coltheart, Rastle, Perry, Langdon and Ziegler, 2001; Harm, and Seidenberg, 2004). The activation of and interaction between these three domains of knowledge seem to significantly depend, among other factors, on the consistency of the mapping between orthography and phonology (Frost and Katz, 1992; Grainger and Ziegler, 2011; Ziegler and Goswami, 2005). Some languages (e.g., Greek, Italian, Spanish, etc...) have shallow orthographies with consistent relationships between graphemes and phonemes. As a consequence, orthographic input systematically activates phonological representations (Ellis and Hooper, 2001; Goswami et al., 1997, 1998). Other languages (e.g., English, French) have deep orthographies with inconsistent sound-spelling correspondences making the activation of phonological representations from script a less reliable option

(Goswami et al., 1998; Landerl, Wimmer and Frith, 1997). Still other languages, in particular Semitic languages like Hebrew and Arabic, instantiate their orthographies in two versions: a shallow and a deep orthography (Abu-Rabia, 2001, 2007). In the shallow orthography, words are “vowelless” with the diacritics representing the short vowels (Azzam, 1984), thereby providing a one-to-one mapping between graphemes and phonemes. In the deep orthography system, consonants and three long vowels are represented by letters, but the three remaining short vowels are omitted (i.e., “vowelless”) thereby generating a high degree of inconsistency between graphemes and phonemes (Katz and Frost, 1992).

There are however some exceptions to the one-to-one mapping between graphemes and phonemes in vowelless words. For instance, the letter *alif* ‘ا’, corresponding to the long vowel/aa/, can be mute in some words (e.g., *كتبا* [katabuu]), “they wrote”, or pronounced as a short vowel in other words (e.g., /i/ as [mi atun] in the word *مائة*, “a hundred”). Conversely, the demonstrative pronoun *ذلك* is pronounced with a long vowel/aa/as [ðaalika] although its orthography does not feature the *alif*. Thus, letters can be pronounced without being written and written without being pronounced. However, in spite of these counterexamples, the vowelless script of Arabic typically presents more regular graphemes to phonemes mapping than other languages (Azzam, 1984; Hansen, 2010). Interestingly, adult Arabic readers are mainly exposed to

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materials written using deep orthography, while shallow orthography is experienced by children in their early years of learning to read or in special reading materials like poetry and religious books.

Against this linguistic background, an interesting question that arises is how can Arabic, or for that matter Hebrew, function equally well with an unvowelled and a vowelled script? Boudelaa and Marslen-Wilson (2005, 2011) have argued that this is linked to the morphological structure of these languages. Arabic is characterized by a non-concatenative morphology whereby every surface form is analyzable into a consonantal root, that conveys semantic meaning, and a word pattern (made up of vowels and of a subset of consonants) conveying morphosyntactic and phonological information. For example, the form *كتم* [katama] conceal, hide (in the sense of hiding a secret), consists of the root {ktm} with the general meaning of hiding and the word pattern {fa ala} with the morphosyntactic meaning perfective, active. The word pattern vowels are essentially conveyed as diacritics in the vowelled script. There is evidence to suggest (a) that Arabic native speakers systematically parse the orthographic form into a root and word pattern and (b) that lexical access processes are initially oriented towards the root with information about the word pattern (i.e., the vowels) becoming available at a later stage (Boudelaa and Marslen-Wilson, 2005, 2011).

To date there is behavioral evidence suggesting that reading shallow orthographies relies upon phonological decoding of small orthographic units such as phonemes and phones, whereas reading deep orthographies depends upon the direct identification of larger orthographic units like syllables, or onsets and rimes (Cossu, Shankweiler, Liberman, Katz, and Tola, 1988; Frost, 1994, 1995; Grainger and Ziegler, 2011; Ziegler and Goswami, 2005; Seidenberg, 2011). In Arabic, reading accuracy has been found to be significantly higher for the shallow (vowelled) orthography than for the unvowelled (deep) orthography, both in normal children and in dyslexic children of various age groups (Abu-Rabia, 2007).

Results of experiments using neuro-imaging suggest that shallow and deep orthographies involve different neural substrates (Bourisy et al., 2013; Paulesu et al., 2000). Orthographic depth also has measurable effects on at least two components of the Event Related Potentials (ERPs): the N170 and the N320 component (Bentin et al., 1999; Proverbio and Zani, 2003) that are of most interest here. For instance, Simon et al. (2006) showed that the N170 amplitude is influenced by orthographic familiarity and word frequency. More recently, Taha et al. (2012) reported that the amplitude of the N170 recorded from Arabic adult readers was larger and its latency shorter to words written using the most familiar connected orthographic patterns than to words using less familiar unconnected letters patterns. Bar-Kochva and Breznitz (2012) showed that vowelled Hebrew words were associated with larger amplitude and longer latency of the N170 component at occipito-temporal sites than unvowelled Hebrew words. Where the N320 is concerned, Simon, Bernard, Lalonde and Rebaï (2006) report an N320 response to French, but not to unvowelled Arabic stimuli, suggesting that French requires the use of grapheme–phoneme conversion while Arabic does not (Ziegler et al., 2003).

Collectively these studies provide interesting insights into the temporal and topographic properties of orthographic processing in Semitic languages. However, they fall short of making any claims about the potential influence of vowelling on semantic processing. Specifically does the presence of vowel diacritics speed up semantic processing? The aim of the present study is to fill this gap by asking whether orthographic depth (vowelling) and semantic processing are independent or interactive. For this end, we used a semantic priming task, in which participants are asked to judge whether two sequentially presented words, a prime (e.g., drink) and a target (e.g., TEA) are semantically related or not. This task is particularly well suited to our purposes since subjects need to access their semantic knowledge in order to carry out the task, and this will allow us to determine if the time course and topography of access to semantic knowledge are modulated by vowelling.

Previous results using this paradigm have repeatedly shown that semantically related words are associated with faster RTs and lower error rates compared to unrelated words (e.g., Khateb et al., 2003, 2010). Moreover, previous results using the ERPs method have demonstrated that semantically unexpected words in sentence contexts (Kutas and Hillyard, 1980) or in word pairs (Bentin et al., 1985; Holcomb and Neville, 1990; Khateb et al., 2003, 2010) elicit larger negative ERP components with maximum amplitude 400 ms post-stimulus onset (i.e., N400 component) than semantically expected or related words (for reviews see Hagoort, 2008; Kutas et al., 2006; Kutas and Federmeier, 2011).

Interestingly, the N400 effect has been documented in many languages including Dutch (e.g., Brown and Hagoort, 1993; Gunter et al., 1997), English (e.g., Kutas and Hillyard, 1980; Boddy, 1981; Bentin et al., 1985), Finnish (e.g., Juottonen, Revonsuo and Lang, 1996), French (e.g., Besson and Macar, 1987; Khateb et al., 2003, and 2010), German (e.g., Heinze, Münte and Mangun, 1994; Günter et al., 1997), Italian (Cobianchi and Giaquinto, 1997), Japanese (Ueno and Kluender, 2009), Mandarin Chinese (e.g., Lee, Tsai, Huang, Hung and Tzeng, 2006; Ye, Luo, Friederici and Zhou, 2006), Norwegian (e.g. von Koss Torkildsen, Syversen, Gram Simonsen, Moen and Lindgren, 2007), Spanish (Wicha et al., 2003), Swedish (e.g., Ors, Lindgren, Berglund, Hägglund, Rosen and Blennow, 2001) but, to our knowledge, it has never been tested in Arabic (Bourisy et al., 2013) using the fMRI method and Taha et al. (2012) mainly examined the N170 component.

In summary, the specific aims of the present experiment were to determine (a) whether semantically priming effects can be demonstrated in Arabic both on RTs and on the N400 component and (b) whether the effects of orthographic (vowelled-unvowelled) and semantic factors (related-unrelated) on behavior and on the amplitude/latency of the N400 are independent or interactive. We hypothesized that unvowelled words can be more difficult to process (i.e., associated with slower RTs, higher error rate and larger N400 components) than vowelled words because different unvowelled words can share an identical consonantal structure but have different pronunciations and meanings. Alternatively however, it is conceivable that vowelled words prove to be more difficult to process (and consequently yield slower RTs, higher error rate and larger early perceptual and cognitive ERPs components, N1, P2, N2) than unvowelled words because they are visually more complex (due to the presence of diacritical marks) and less familiar to fluent adult Arabic readers who mainly read unvowelled words. Additionally, these two factors, visual complexity and familiarity, may interfere with semantic priming effects.

2. Methods

2.1. Participants

A total of 20 students (10 women), aged between 20 and 34 years old (mean: 27 years; sd: 9.89), from the University Mohammed V Agdal, in Rabat, Morocco, were tested in this experiment. They were all right-handed and without neurological disorders. Three participants were excluded from final data analysis because of a high number of trials contaminated by ocular and muscular artifacts. All participants use Arabic on a daily basis and were Master or PhD. students (mean number

Table 1

Examples of experimental items used in the experiment. For each example, the word in Arabic, a phonological transcription using IAP symbols and an English gloss are indicated.

	Prime		Target
	Related	Unrelated	
Vowelled	سَرِير [sariirun] Bed	عَسْكَرِي [askariYYun] Military	وَسَادَةٌ [wisaadatun] Pillow
Unvowelled	سَرِير [sariirun] Bed	عَسْكَرِي [askariYYun] Military	وَسَادَةٌ [wisaadatun] Pillow

Table 2

Lexical characteristics of the stimuli used in the experiment. Mean and standard deviation (in parenthesis) are provided for each variable. Logged Surface and bigram frequencies are computed from the ARALEX database and number of reading from "Almaany" dictionary accessible at: <http://www.almaany.com>.

	Prime		Target
	Related	UNRELATED	
Number of letters	3.92 (0.98)	3.95 (0.91)	3.94 (0.91)
Logged	1.35	1.33	1.39
Surface frequency	(1.74)	(1.86)	(1.76)
Logged	3.56	3.56	3.61
Bigram-frequency	(3.54)	(2.54)	(3.65)
Number of reading	1.89 (1.74)	1.86 (1.72)	1.73 (1.29)

of years of education: 16 years; sd: 4.24) with no reading problems. The experience lasted 1.45 h on average. This experiment was approved by the ethics committee of the Mohammed V Agdal University and all participants gave their written consent to participate in the experiment. They were paid for their participation.

2.2. Stimuli

A total of 256 Arabic prime–target word pairs were used. Of these, 128 pairs were presented in the vowelised condition, with 64

semantically related pairs and 64 semantically unrelated pairs. The same 128 word pairs were presented in the unvowelised condition, again with 64 semantically related pairs and 64 semantically unrelated pairs. For both vowelised and unvowelised pairs, two lists were constructed so that across lists, the same target word was paired once with a semantically related prime and once with a semantically unrelated prime (see Table 1 for an example). The lists were counter-balanced across participants. The prime–target relationship for each pair was pre-tested in a pilot study (see Appendix A for full list of materials). In the pilot study, a total of 270 word pairs were presented to 28 participants who were asked to decide whether the two words were semantically related or unrelated on a binary scale. Only those pairs (256) which were judged to be semantically related by 90% of the subjects or more were included in the EEG experiment. Prime and targets words in related pairs shared different kinds of semantic relations. They were semantically or associatively related, members of the same semantic category or synonyms words. Using the Aralex database (Boudelaa and Marslen-Wilson, 2010), we matched our prime words on two important lexical variables. The first is surface word frequency which refers to the frequency of the orthographic string as it occurs in Arabic text. The second is bigram frequency which refers the frequency of each two letters taken together within a word. Finally we matched the priming items on their orthographic ambiguity by computing the number of possible readings each item can lend itself to (see Table 2).

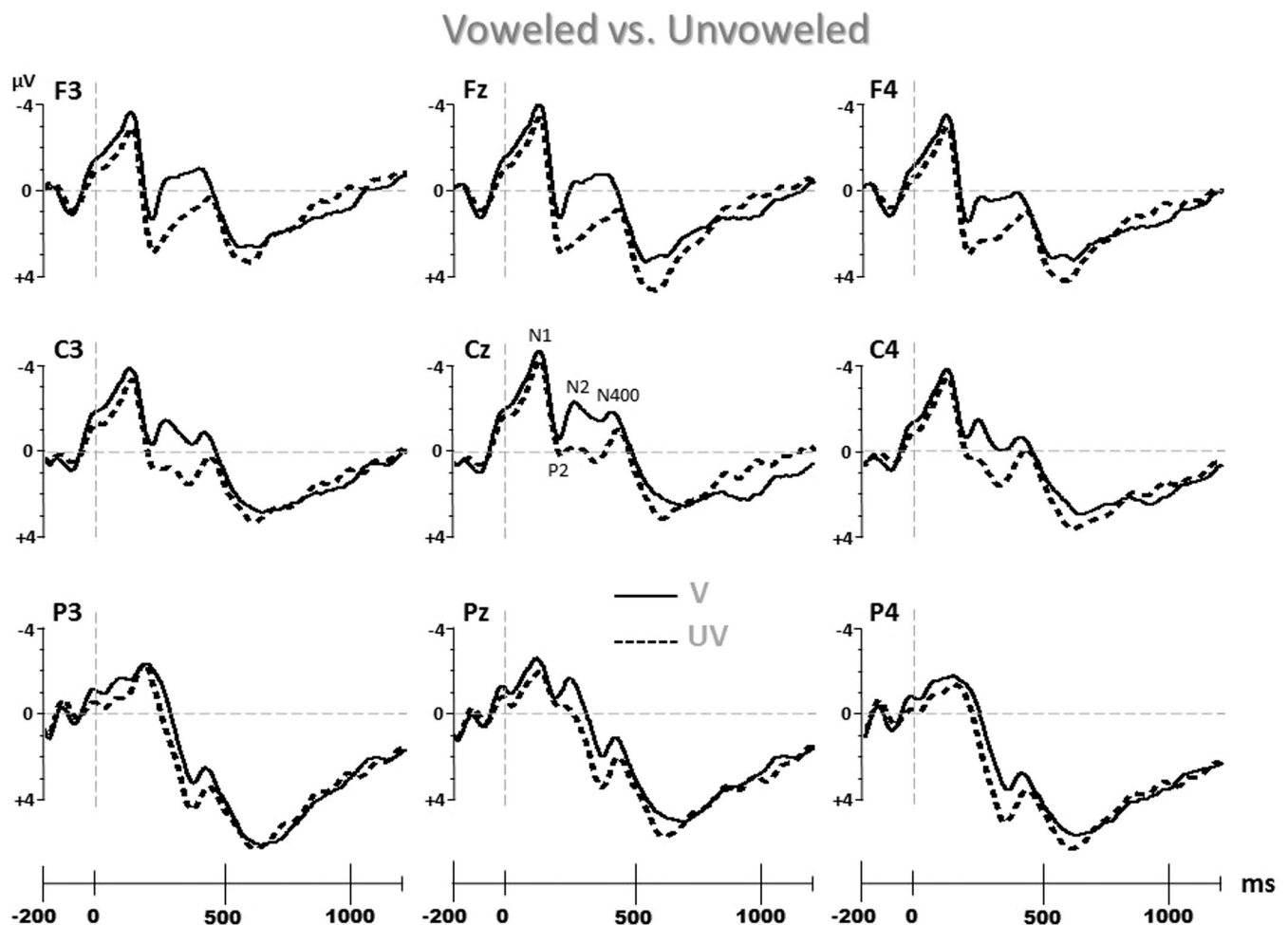


Fig. 1. Vowelling effect. ERPs to vowelised (V; solid line) and to unvowelised words (UV; dotted line) are averaged across semantically related and semantically unrelated words. ERPs are illustrated at nine representative electrodes. On this and subsequent figures, time in milliseconds (ms) is in abscissa and the amplitude of the effects in microvolts (μV) is in ordinate.

2.3. Procedure

Participants were comfortably seated in a Faradized room and were asked to silently read the two words that were successively presented at the center of a computer screen. They had to decide, as quickly and as accurately as possible whether the target word was semantically related to the prime word or not by pressing one of the two response keys. Response hand was counter-balanced across participants.

Vowelled and unvowelled word-pairs were presented in separate blocks of trials (two with vowelled words and two with unvowelled words). An experimental trial consisted of a prime displayed at the center of a computer screen for 500 ms followed by an empty interval of 300 ms, and a target displayed for 2000 ms or until the subject responded. Once participant presses the response key a row of XXXX appears on the screen for 2000 ms and participants were asked to blink several times before the next trial started. In order to familiarize participants with the task, the experiment began with a training session which mimicked the structure of the experiment with 8 words presented in vowelled and unvowelled formats in a related and unrelated condition.

2.4. Recording ERPs

The EEG was amplified using SAI amplifiers (San Diego) and continuously recorded from 24 electrodes mounted on an elastic head cap, and located at standard positions on the left and right hemispheres at

frontal, central, parietal, occipital and temporal locations (10/20 international system; Jasper, 1958): Fz, Cz, Pz, Oz, Fp1, Fp2, F7, F8, F3, F4, FC5, FC6, FC1, FC2, T3, T4, C3, C4, CP5, CP6, CP1, CP2, P3 and P4. The impedance of the electrodes was always lower than 5 k Ω and EEG data were recorded with a 250 Hz sampling frequency. The Electro-Oculogram (EOG) was recorded from an electrode placed under the right eye to detect eye blinks and from two electrodes placed on the left and right mastoids. To be able to compare results with previous literature and to analyze inter-hemispheric differences, the EEG was re-referenced off-line to the average of the left and right mastoids.

3. Data analysis

EEG data were averaged for each participant using EEGLAB (Delorme and Makeig, 2004). Continuous recordings were segmented into 2400 ms duration trials starting 200 ms before stimulus onset (baseline). Trials containing eye movements or muscles artifacts were excluded from further processing. The remaining trials were averaged within each of the four conditions: VR: vowelled related, VNR: vowelled unrelated, NVR: unvowelled related and NVNR: unvowelled unrelated. Finally, data were averaged across participants to obtain the grand-averages.

ERP data were analyzed by computing the mean ERP amplitude relative to a 200-msec baseline in successive latency bands determined from previous results in the literature (Kutas et al., 2006; Rugg and Coles, 1995) and from visual inspection of the waveforms. These latency

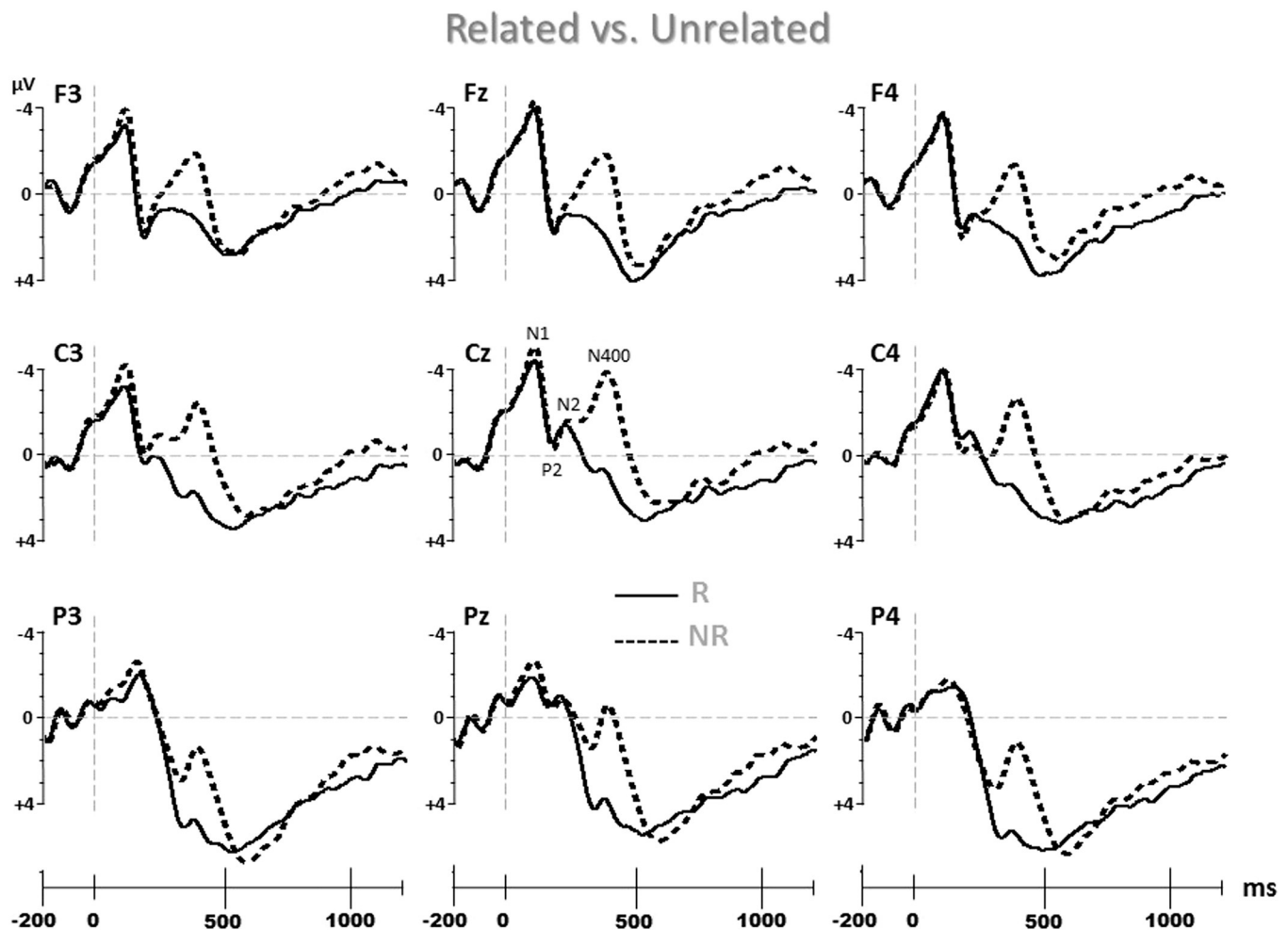


Fig. 2. Semantic priming effect. ERPs to semantically related (R; solid line) and to semantically unrelated words (NR; dotted line) are averaged across vowelled and unvowelled words. ERPs are illustrated at nine representative electrodes.

bands corresponded to the ERP components of main interest that were modulated by the vowelling and semantic relatedness factors: N100 (0–100 ms) and P200 (100–200 ms) components (see Figs. 1 and 3) as well as the N200 (200–300 ms) and N400 (300–600 ms) components (Figs. 2 and 4). Analyses of Variance (ANOVAs) were conducted separately at midline and lateral electrodes. ANOVA at midline electrodes included semantic relatedness (related vs unrelated), vowelling (vowelled vs. unvowelled) and electrodes (4 levels: Fz, Cz, Pz, and Oz) as within-subject factors. ANOVA at lateral electrodes included Semantic relatedness, Vowelling along with the factors Hemisphere (2 levels: left, right) and Regions Of Interest (ROI, 3 levels: fronto-central, central and parietal) as within-subject factors. When the effects of Semantic (related vs. unrelated) were found to interact with the effects of Vowelling and/or Electrodes/ROI/Hemisphere, Tukey tests were used for post-hoc comparisons. All *p* values were adjusted with the Greenhouse–Geisser epsilon correction for nonsphericity.

4. Results

4.1. Behavioral data

Two-way ANOVA including Semantic (related vs unrelated) and Vowelling (vowelled vs unvowelled) as within-subject factors was conducted on error rates and RTs data. The main effect of Semantic was significant ($F(1,15) = 5.20, p < .04$) with semantically related words being associated with shorter RTs (699 ms) than semantically unrelated words (741 ms). By contrast, the main effect of Vowelling was not significant ($F(1,15) = 1.05, p > .30$) with vowelled (713 ms) and

unvowelled words (740 ms) yielding comparable latencies. The Semantic by Vowelling interaction was not significant ($F < 1$).

The percentage of errors was not significantly different for semantically related (8.17%) and unrelated words (6.34%; main effect of Semantic: $F(1,15) = 1.11, p = 0.30$) and for vowelled (6.61%) and unvowelled words (7.90%; main effect of Vowelling: $F < 1$). The Semantic by Vowelling interaction was not significant ($F < 1$).

4.2. Electrophysiological data

4.2.1. The N1 component

The N1 component was larger for vowelled ($-2.31 \mu\text{V}$) than for unvowelled words ($-1.74 \mu\text{V}$; main effect of Vowelling: $F(1,15) = 8.40, p < .01$, see Fig. 1). By contrast, neither the main effect of Semantic nor the Semantic by Vowelling interaction were significant ($F < 1$ in both cases, see Fig. 2). Similarly, at lateral electrodes, the N100 component was larger for vowelled ($-1.99 \mu\text{V}$) than for unvowelled words ($-1.32 \mu\text{V}$; main effect of Vowelling: $F(1,15) = 11.23, p = .004$; see topographic maps on Fig. 5). Neither the main effect of Semantic nor the Semantic by Vowelling interaction were significant ($F < 1$ in both cases).

4.2.2. The P2 component

No significant effects were found at midline electrodes (Vowelling: $F(1,15) = 3.24, p < .09$, Semantic: $F(1,15) = 1.21, p < .28$ and Vowelling by Semantic: $F < 1$). However, at lateral electrodes, the P200 component was larger for Unvowelled ($-0.03 \mu\text{V}$) than for Vowelled words ($-1.64 \mu\text{V}$; main effect of Vowelling: $F(1,15) = 4.65, p < .05$, see Figs. 1 and 5). Moreover, the Semantic by Laterality interaction was

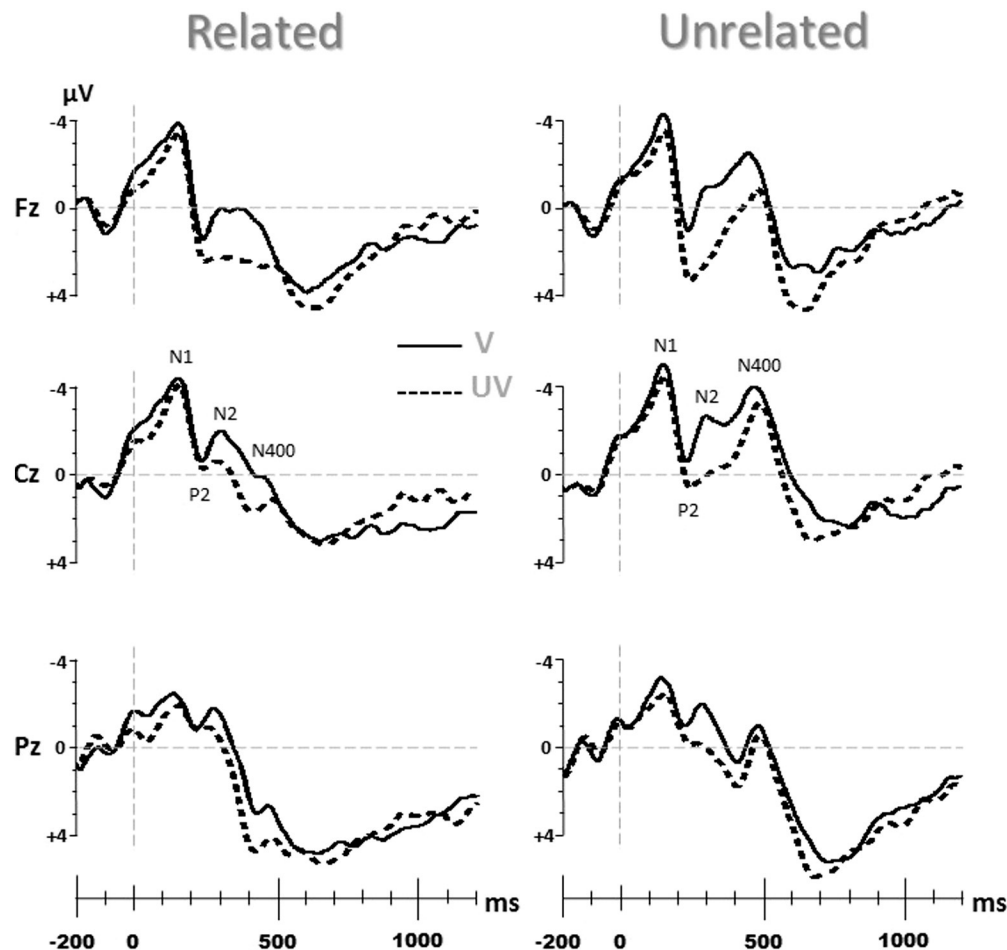


Fig. 3. ERPs to vowelled (solid line) and to unvowelled words (dotted line) are presented separately for semantically related (left) and for semantically unrelated words (right) at midline electrodes.

also significant ($F(1,15) = 5.36, p < .03$) with larger P200 to semantically related ($-1.03 \mu\text{V}$) than to unrelated words ($-1.61 \mu\text{V}$) over the left but not over the right hemisphere ($-1.35 \mu\text{V}$; see Figs. 2 and 5). Neither the main effect of Semantic nor the Semantic by Vowelling interaction were significant ($F < 1$ in both cases; see Fig. 2).

4.2.3. The N2 component

The N200 component was larger for Vowelled ($-0.80 \mu\text{V}$) than for unvoiced words at midline electrodes ($1.41 \mu\text{V}$; main effect of Vowelling: $F(1,15) = 9.61, p < .007$; see Fig. 1). Neither the main effect of Semantic nor the Semantic by Vowelling interaction were significant ($F(1,15) = 1.71, p < .20$ and $F < 1$, respectively). Similarly, at lateral electrodes, the N200 component was also larger for vowelless ($-0.48 \mu\text{V}$) than for unvoiced words ($1.56 \mu\text{V}$; main effect of Vowelling: $F(1,15) = 9.65, p < .007$; see topographic maps on Fig. 5). The difference was larger over the left ($2.25 \mu\text{V}$) than over the right hemisphere ($1.82 \mu\text{V}$; Vowelling by Laterality: $F(1,15) = 4.76; p < .04$). Neither the main effect of Semantic nor the Semantic by Vowelling was significant ($F < 1$ in both cases).

4.2.4. The N400 component

The N400 component was larger for semantically unrelated words ($1.30 \mu\text{V}$) than for related words ($3.24 \mu\text{V}$; main effect of Semantic: $F(1,15) = 8.61, p < .01$; see Fig. 2). By contrast, neither the main effect of Vowelling nor the Semantic by Vowelling interaction were significant ($F(1,15) = 2.84, p < .11$ and $F < 1$, respectively; see Figs. 3 and 4). Similarly, at lateral electrodes the N400 component was larger for

semantically unrelated ($1.23 \mu\text{V}$) than for related words ($2.83 \mu\text{V}$; main effect of Semantic: $F(1,15) = 8.97, p < 0.009$). Moreover, the N400 was slightly larger over the right ($1.92 \mu\text{V}$) than over the left hemisphere ($1.26 \mu\text{V}$; Semantic by Laterality interaction: $F(1,15) = 5.66, p < .03$; see Figs. 2 and 5). Neither the main effect of Vowelling nor the Semantic by Vowelling interaction was significant ($F(1,15) = 2.33, p < .14$ and $F < 1$, respectively).

5. Discussion

The results are clear-cut: There is a vowelless effect on the early N1, P2 and N2 components and a semantic priming effect on both RTs and on the N400 component. Moreover, the Vowelling by Semantics interaction is not significant either in the behavioral or electrophysiological measures. The implications of these findings are considered in the following discussion.

The first goal of the present experiment was to determine whether semantically related Arabic words are processed faster and elicit smaller N400 components than semantically unrelated words, as has been reported in many other languages (see Kutas and Federmeir, 2011, for review). Our results show semantic relatedness effects in Arabic with primed targets yielding faster RTs than unprimed targets. Additionally, primed Arabic words elicit smaller N400 components than unprimed Arabic words. This priming effect starts at around 300 ms post-word onset and is maximal at around 400 ms, as is typically reported in the literature. Consistent with previous results, the N400 effect are slightly larger over the right than the left hemisphere (e.g., Kutas and Hillyard,

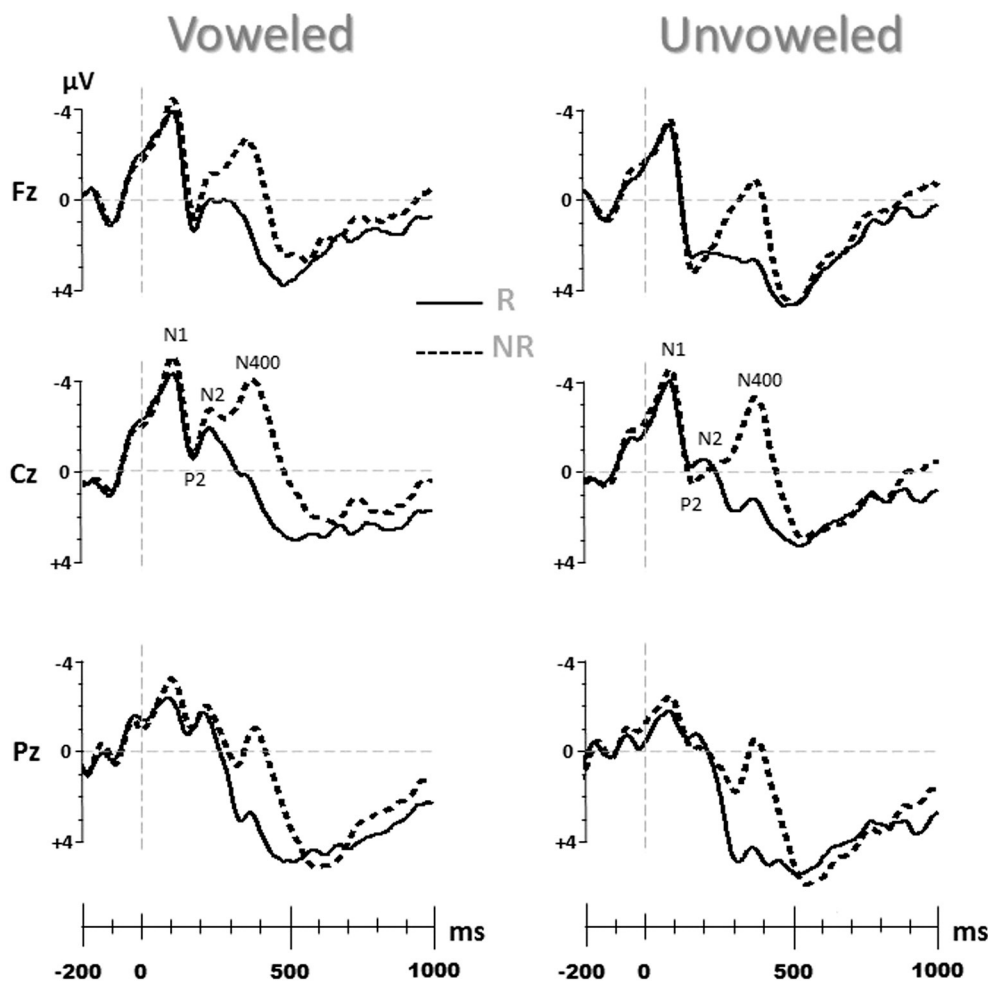


Fig. 4. ERPs to semantically related (solid line) and semantically unrelated words (dotted line) are presented separately for vowelless (left) and for unvoiced words (right) at midline electrodes.

1980, 1988). These results are interesting not only in showing that the N400 effect can be elicited by Arabic as well as by Latin characters, but also because they suggest that the N400 effect abstracts away from other low level factors such as the direction of reading/writing, which is from right to left in Arabic words but from left to right in Latin script.

Our results are compatible with two competing accounts of the N400 effects: the *integration view* and the *anticipation view* (for further detail see Cermolacce et al., 2014 and Van Petten and Luka, 2012). On the integration view, semantically related words are associated with faster RTs and smaller N400 components because they are easier to integrate within the context of the prime (Hagoort, 2008; Van Berkum et al., 2005; Van Petten and Luka, 2012). According to the anticipation view, the prime word pre-activates the representation of semantically related target words in memory before they are actually presented so that upon presentation they are easier to process (DeLong et al., 2005; Federmeier, 2007; McClelland and Elman, 1986; Morton, 1969; Collins and Loftus, 1975). Our goal was not to adjudicate between these two views, but to examine the behavioral and neurophysiological correlates of semantic processing in Arabic. Now that we have demonstrated that such effects hold for this language, future research can build on this to test for different models of word recognition and for specific issues related to the direction of reading and reading preferences. Further studies should also use different tasks (e.g., lexical decision task) and different stimulus onset asynchronies between prime and target to disentangle the automatic and more controlled aspects of semantic priming effects in Arabic.

The second goal of our experiment was to determine whether the effects of the orthographic (vowelled–unvowelled) and semantic (related–unrelated) factors are independent or interactive. Our results reveal no vowelism by semantic interaction either in latency or accuracy data, suggesting that the semantic priming effect is equivalent for vowelled and unvowelled words. This outcome is consistent with previous results from Hebrew where RTs and percent errors were not significantly different for vowelled and unvowelled words (Bentin and Frost, 1987; Frost, 1994, 1995; Koriat, 1984). This suggests that performance in the semantic task is not modulated by the presence/absence of

vowel diacritics. Importantly, the N400 effect is not significantly different for unvowelled and vowelled words suggesting that there is a substantial degree of independence between the effects of visual orthography and semantics. Since the N400 amplitude is typically modulated by semantic processing difficulty (e.g., Kutas et al., 2006), the similarity of the N400 in both conditions indicates that unvowelled words are as easy to process as vowelled words at the semantic level, possibly because all words are high frequency and none of the participants reported problems recognizing them.

The absence of an N400 difference across the vowelled–unvowelled contrast supports the general view that reading in Arabic is oriented towards and dominated by processes of consonantal root extraction that are required for both vowelled and unvowelled words (Boudelaa and Marslen-Wilson, 2005, 2012). Specifically, Boudelaa and Marslen-Wilson (2005) used incremental masked priming to show that prime and target words sharing the consonants of the root (e.g., [maktab]–[kitaab] *office-book*) show reliable priming at a Stimulus Onset Asynchrony (SOA) of 32, 48, 64 and 80 ms, while primes and targets sharing a word pattern (e.g., [kataba]–[xaraja] *write-go out*) show facilitation only at 48 ms. This was interpreted as suggesting that information about the root consonants is used prior to information about the word pattern vowels and for a longer period of time. This interpretation found support in a follow-up experiment by Boudelaa and collaborators (2009) using the Mismatch Negativity (MMN) paradigm (Näätänen et al., 2007; Kujala, et al., 2007). In that study the results showed that word pairs differing by a root consonant elicited an MMN response at 160 ms after their deviation point, while items differing by a word pattern vowel elicited an MMN response at 250 ms after the deviation point (Boudelaa et al., 2009). It will be of interest in further experiments to vary word frequency to determine whether the effects of orthographic depth and semantic priming are more likely to interact for low than for high frequency words.

Our results using a semantic task contrast with those reported by Bar-Kochva and Breznitz (2012) using a lexical decision task. Rather than an N400 component, Kochva and Breznitz (2012) report a larger P3 amplitude for unpointed (unvowelled) than for pointed (vowelled)

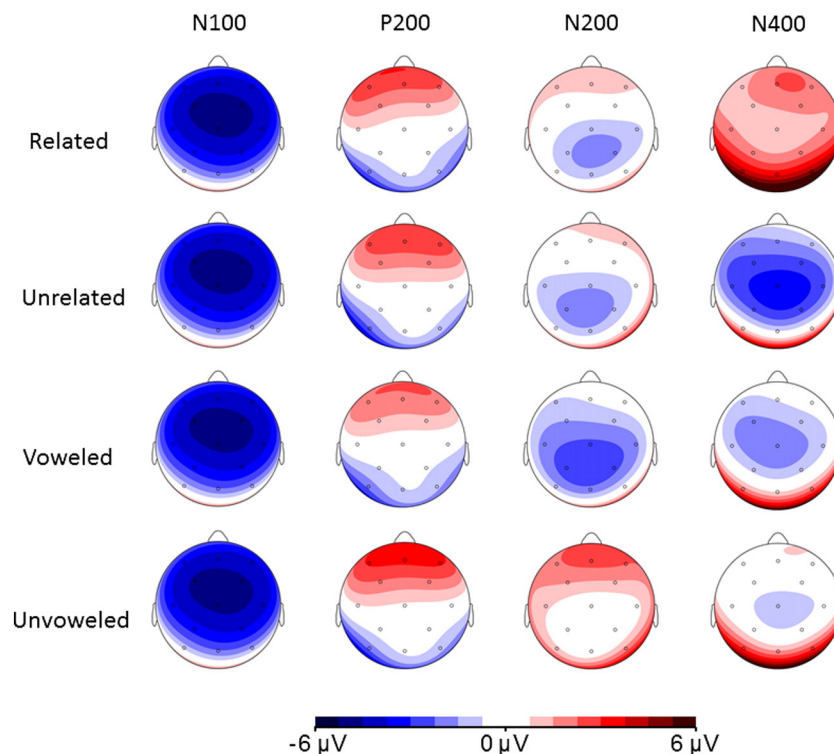


Fig. 5. Topographic maps for each ERP component of interest elicited by the target words in the four experimental conditions.

Hebrew words. This result is surprising insofar as real words and pronounceable pseudo-words typically elicit N400 components, unlike unpronounceable nonwords that elicit P3 components (e.g., Ziegler et al., 1997). While the authors did not discuss this issue, they claimed that the decrease of the P3 amplitude for vowelised words could reflect reduced processing efforts when dealing with vowelised words which are phonologically fully specified, while the larger the P3 response was attributed to the phonologically underspecified nature of the unvowelised words which would require more processing efforts. The different pattern of results (P3 vs N400) between our experiment and Bar-Kochva and Breznitz's (2012) may be due to the tasks used in the two studies, or it may simply reflect a genuine cross-linguistic difference between Arabic and Hebrew. It will be interesting to compare lexical decision and semantic priming tasks (within subjects) with Hebrew and Arabic words (between-subjects) to disentangle the effects of each factor.

6. Conclusion

Our findings show that the presence or absence of vowel diacritics does not affect the N400 component thereby suggesting independent processing of the orthography and semantics. However, processing within the N400 time window may largely depend on the uptake of information from consonants that are always present in both types of orthography. Future research will have to adjudicate between these two interpretations.

Appendix A. List of words used in the experiment. For each word, we provide a vowelised Arabic word with an unvowelised version underneath it along with a phonetic transcription and an English gloss.

Unrelated prime	Related prime	Target
بنت بنت [bintun]	ماندة ماندة [maa idatun]	كرسي كرسي [kursiyyun]
Girl	Table	Chair
عسكري عسكري [ʔaskariyyun]	سري سري [sariirun]	وسادة وسادة [wisaadatun]
Military	Bed	Pillow
رجل رجل [razulun]	دفتر دفتر [daftarun]	قلم قلم [qalamun]
Man	Notebook	Pencil
شرطي شرطي [ʔurtʔiyyun]	سيورة سيورة [sabbauratun]	طباشير طباشير [tʔabaʔiirun]
Police officer	Black-board	Chalk
عم عم [ʔammun]	شعر شعر [ʃaʔrun]	منشط منشط [muʃʔun]
Uncle	Hair	Comb
أستاذ أستاذ [ustaaʔun]	منشار منشار [minʃaarun]	خشبي خشبي [xʃabun]
Professor	Saw	Wood
طباخ طباخ [tʔabbaaxun]	مطرقة مطرقة [mit raqatun]	مسمار مسمار [mismaarun]
Cook	Hammer	Nail
أب أب [abun]	نافذة نافذة [naafiʔatun]	زجاج زجاج [zuʒaaʒun]

(continued)

Unrelated prime	Related prime	Target
Father	Window	Glass
خروف خروف [xaruufun]	سروال سروال [sirwaalun]	فميص فميص [qamiisʔun]
Sheep	Pants	Shirt
أخ أخ [axun]	صورة صورة [sʔuuratun]	إطار إطار [itʔaarun]
Brother	Photo	Frame
قفل قفل [quflun]	إبريق إبريق [ibriiqun]	شاي شاي [ʃaayun]
Lock	Tea-pot	Tea
سحاب سحاب [saħaabun]	أحذية أحذية [aħʔiyatun]	جوارب جوارب [ʒawaaribun]
Clouds	Shoes	Socks
محام محام [muħaamin]	صياغة صياغة [sʔibaa atun]	فرشاة فرشاة [furʃaatun]
Lawyer	Painting	Brush
مشتري مشتري [muʃtarin]	قهوة قهوة [qahwatun]	فنجان فنجان [finʒaanun]
Buyer	Coffee	Cup
منشار منشار [minʃaarun]	صيدلية صيدلية [sʔaydaliyyatun]	دواء دواء [dawaa un]
Saw	Pharmacy	Drug
رياضي رياضي [riyaadʔiyyun]	عروس عروس [ʔaruu:sun]	حناء حناء [hinnaa un]
Athlete	Bride	Henna
سري سري [sariirun]	جمل جمل [ʒamalun]	صحراء صحراء [sʔa ħraa u]
Bed	Camel	Desert
دفتر دفتر [daftarun]	سمك سمك [samakun]	بحر بحر [baħrun]
Notebook	Fish	Sea
سيورة سيورة [sabbauratun]	أرنب أرنب [arnabun]	جزر جزر [ʒazarun]
Black-board	Rabbit	Carrot
سروال سروال [sirwaalun]	أفعى أفعى [afʔaa]	سم سم [summun]
Pants	Snake	Venom
بقال بقال [baqqaalun]	ذئب ذئب [ði bun]	غابة غابة [ʔaabatun]
Shop-assistant	Wolf	Forest
صورة صورة [sʔu:ratun]	ليل ليل [laylun]	قمر قمر [qamarun]
Photo	Night	Moon
نافذة نافذة [naafiʔatun]	سردين سردين [sardiinun]	علبة علبة [ʔulbatun]
Window	Sardines	Can
جمل جمل [ʒamalun]	بناء بناء [bannaa un]	منزل منزل [manzilun]
Camel	Builder	House
مطرقة مطرقة [mitʔaqatun]	مطر مطر [matʔarun]	رعد رعد [raʔʔun]
Hammer	Rain	Thunder
أسد أسد [asadun]	مخبزة مخبزة [maxbazatun]	حلوى حلوى [ħalwaa]
Lion	Bakery	Sweets
حصان حصان [ħisʔaanun]	بنك بنك [bankun]	مال مال [maalun]

(continued)

Unrelated prime	Related prime	Target
Horse	Bank	Money
صباغة	عقد	عقود
صباغة	عقد	عقود
[s'ibaayʔatun]	[ʕiqdun]	[ʕunuuqun]
Painting	Necklace	neck
قهوة	جزار	لحم
قهوة	جزار	لحم
[qahwatun]	[zazzaarun]	[lahmun]
Coffee	Butcher	Meat
جزار	نحل	عسل
جزار	نحل	عسل
[zazzaarun]	[nahlnun]	[ʕasalnun]
Butcher	Bees	Honey
دودة	بقرة	حليب
دودة	بقرة	حليب
[duudatun]	[baqaratun]	[haliibun]
Caterpillar	Cow	Milk
شعر	حزرون	قوقعة
شعر	حزرون	قوقعة
[ʕaʕrun]	[halazuunun]	[qawqaaʕatun]
Hair	Snail	Shell
سمك	دودة	حرير
سمك	دودة	حرير
[samakun]	[duudatun]	harii run
Fish	Caterpillar	Silk
أرنب	زهرة	أزهار
أرنب	زهرة	أزهار
[arnabun]	[ahratan]	[azhaarun]
Rabbit	Flower	Butterfly
أفعى	طيار	مروحية
أفعى	طيار	مروحية
[afʕaa]	[t'ayyaarun]	[mirwahiyatun]
Snake	Pilot	Helicopter
مهد	شرطي	لص
مهد	شرطي	لص
[mahdun]	urt'iyyun	lis'un
Cradle	Policeman	Thief
ليل	طبيب	ممرضة
ليل	طبيب	ممرضة
[laylnun]	[t'abiibun]	mumarrid'atun
Night	Doctor	Nurse
سردين	رجل	امرأة
سردين	رجل	امرأة
[sardiinun]	[raʕulun]	ʔimraʔatun
Sardines	Man	Woman
عقد	بنت	ولد
عقد	بنت	ولد
[ʕiqdun]	[bintun]	[waladun]
Necklace	Girl	Boy
نحل	سحاب	سمااء
نحل	سحاب	سمااء
[nahlnun]	[sahaabun]	[samaa un]
Bees	Cloud	Sky
بقرة	أستاذ	تلميذ
بقرة	أستاذ	تلميذ
[baqaratun]	[ustaaʔun]	[tilmii:ʔun]
Cow	Professor	Student
أزهار	طباخ	مطعم
أزهار	طباخ	مطعم
[azhaarun]	[t'abbaaxun]	[mat'ʕamun]
Butterfly	Cook	Restaurant
ذئب	أب	أم
ذئب	أب	أم
[ʔi bun]	[abun]	[ummun]
Wolf	Father	Mother
عش	رياضي	مدرب
عش	رياضي	مدرب
[ʕuʕʕun]	[riyaad'iyyun]	[mudarribun]
Nest	Athlete	Coach
قط	أخ	أخت
قط	أخ	أخت
[qit't'un]	[axun]	[uxtnun]
Cat	Brother	Sister
دجاجة	عم	الة
دجاجة	عم	الة
[daʕaaʕatun]	[ʕammun]	[xaalatun]

(continued)

Unrelated prime	Related prime	Target
Hen	Uncle	Aunt
بناء	عسكري	جندي
بناء	عسكري	جندي
[bannaa un]	[ʕaskariyyun]	[ʕundiyyun]
Builder	Military	Soldier
بطة	محام	منهم
بطة	محام	منهم
[bat't'atun]	[muhaamin]	[muttahamun]
Duck	Lawyer	Defendant
ماندة	مشتري	بائع
ماندة	مشتري	بائع
[maa idatun]	[muʕtarin]	[baa iʕun]
Table	Buyer	Seller
معزاة	يقال	زبون
معزاة	يقال	زبون
[miʕzaatun]	[baqqaalun]	[zabuunun]
Kid	Shop-assistant	Customer
أحذية	قفل	مفتاح
أحذية	قفل	مفتاح
[ahʔiyatun]	[quflun]	[miftaahun]
Shoes	Lock	Key
ذباية	رئيس	وزير
ذباية	رئيس	وزير
[ʔubaabatun]	[ra iisun]	[waziirun]
Fly	President	Minister
فيل	ملك	أمير
فيل	ملك	أمير
[fiulun]	[malikun]	[amiirun]
Elephant	King	Prince
إبريق	قط	كلب
إبريق	قط	كلب
[ibriiqun]	[qit't'un]	[kalbun]
Tea-pot	Cat	Dog
مطر	دجاجة	ديك
مطر	دجاجة	ديك
[mat'arun]	[daʕaaʕatun]	[diikun]
Rain	Hen	Cock
مخبرة	أسد	نمر
مخبرة	أسد	نمر
[maxbazatun]	[asadun]	[namirun]
Bakery	Lion	Tiger
بنك	بطة	إوزة
بنك	بطة	إوزة
[bankun]	[bat't'atun]	[iwazatun]
Bank	Duck	Goose
صيدلية	خروف	نعجة
صيدلية	خروف	نعجة
[ʕaydaliyyatun]	[xaruufun]	[naʕʕatun]
Pharmacy	Sheep	Female-sheep
طيار	معزاة	عنزة
طيار	معزاة	عنزة
[t'ayyaarun]	[miʕzaatun]	[ʕanzatun]
Pilot	Kid	Goat
طبيب	حصان	فرس
طبيب	حصان	فرس
[t'abiibun]	[his'aanun]	[farasun]
Doctor	Horse	Mare
ذباية	ذباية	بعوضة
ذباية	ذباية	بعوضة
[ra iisun]	[ʔubaabatun]	[baʕuud'atun]
President	Fly	Mosquito
ملك	فيل	غزالة
ملك	فيل	غزالة
[malikun]	[fiulun]	[vazaalatun]
King	Elephant	Gazelle
حزرون	مهد	رضيع
حزرون	مهد	رضيع
[halazuunun]	[mahdun]	[rad'i:ʕun]
Snail	Cradle	Infant
عروس	عش	عصفور
عروس	عش	عصفور
[ʕaruu:sun]	[ʕuʕʕun]	[ʕus'fuurun]
Bride	Nest	Bird

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