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ARTICLE

Visual similarity effects in the identification of Arabic letters: evidence with masked priming

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Abstract
Research using masked priming and parafoveal preview techniques has shown that visual letter similarity has an impact on word processing during the initial stages in Latin-derived scripts. However, these effects appear to be absent in Arabic. One reason for this discrepancy could be attributed to the distinctive features of the Arabic script, which includes numerous letters sharing a basic form while varying in the location or number of diacritics. To shed light on this issue, the present study employed Arabic letters rather than words in two masked priming experiments: an alphabetic decision task and a letter-matching task. Both experiments showed that visually similar letters were more effective as primes than visually dissimilar letters. These findings suggest that the processes of letter identification in Arabic and Latin scripts may be roughly alike, implying that differences in visual letter similarity across scripts may arise at later stages of processing.

Keywords: Arabic reading; letter encoding; masked priming; visual similarity

1. Introduction

There is a widespread consensus that orthographic processing plays a crucial role during visual word recognition in languages that use the Latin script. This process involves encoding both the abstract letter identities and their positions, enabling the differentiation of neighboring words like *mouse* and *moose* or *causal* and *casual* (for review, see Grainger, 2018). An influential modeling perspective in the fields of letter and word recognition in Latin-based orthographies (Dehaene et al., 2005; Grainger et al., 2008) posits a hierarchical arrangement of progressively more complex layers of neurons in the occipitotemporal pathway, akin to leading models of invariant object recognition (Riesenhuber & Poggio, 1999). In the lowermost layers, simple arrays of neurons are assigned to respond to basic features in letters, such as horizontal lines and curves. These arrays are then mapped onto more complex features and combinations, leading to arrays of neurons that respond to shape-specific letters (e.g., a but not *a* or A). Importantly, this mapping progresses to a layer of complex letter neurons that respond to different visual forms of a given letter, such as a, *a*, A, but not e or H. These abstract letter detectors then drive lexical access through mapping onto layers of neurons that respond to ordered sequences of letters and, ultimately, words (see Figure 1 in Dehaene et al.'s, 2005, local combination detector model).

While lexical access in these models is driven by abstract letter representations, the initial encoding of letter identity (and letter order) could be subject to some uncertainty (Dehaene et al., 2005; Dehaene & Cohen, 2007; see also Norris & Kinoshita, 2012). Thus, the letter v in the item *nevtral* may initially activate not only the abstract detectors of *v* but also those of other visually similar letters like *u*. Indeed, the effect of visual letter similarity in the initial stages of letter and word processing has been obtained in various tasks (see Benyhe et al., 2023; Lally & Rastle, 2022; Marcet & Perea, 2017, 2018a; see Gutiérrez-Sigut et al., 2019, for electrophysiological evidence).

One crucial theoretical question in the fields of word recognition and reading is whether the models originally developed for the Latin script can be extended to effectively account for these processes in writing systems with distinct characteristics. Here, we focus on the Arabic script. This script, which is used in multiple languages with diverse linguistic roots (e.g., Arabic [Semitic], Persian [Indo-European], Uyghur [Turkic], Urdu [Indo-Aryan], Balti [Sino-Tibetan], Somali [Afro-Asiatic] Mandinka [Mande]), presents unique features in comparison to the Latin script (see AlJassmi et al., 2021; Hermena & Reichle, 2020, for recent reviews).

First, unlike the Latin script, there are no uppercase letters in Arabic, and letters are read from right to left. Second, and more important for the present study's goals, approximately 80% of all letters in Arabic share their common base form with at least another letter. As shown in Table 1, these forms differ mainly in the number, position and presence of dots (or diacritical marks)[1]; for instance, letters خ /x/ and ج /ʒ/ both derive from the base form of ح /ħ/ (Asaad & Eviatar, 2014; Boudelaa et al., 2020; Perea et al., 2016, 2018). Third, Arabic script employs a semicursive script in which some letters are normatively connected to other letters, but others are not. Letters such as ز exhibit limited visual variations across letter positions. For instance, the letter ز appears in the initial position in زمن [time], and it takes the same shape when it is in

Table 1. List of Arabic letters that share their based letters with other letters along with their IPA codes

Letter 1	IPA code	Letter 2	IPA code	Letter 3	IPA code
ب	/b/	ت	/t/	ث	/θ/
ج	/ʒ/	ح	/ħ/	خ	/x/
د	/d/	ذ	/ð/		
ر	/r/	ز	/z/		
س	/s/	ش	/ʃ/		
ص	/sˤ/	ض	/dˤ/		
ط	/tˤ/	ظ	/ðˤ/		
ع	/ʕ/	غ	/ɣ/		
ف	/f/	ق	/q/		

[1]Note that we use these terms interchangeably throughout the paper.

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the medial position of عزم [determination] as well as in the final position of كنز [treasure] (the target letter is underlined for clarity). In contrast, other letters like ع/ʕ/, display very distinct visual forms (e.g., عمل [work] in the initial position, بعل [husband] in the medial position, بلع [swallow] in the final position and فرع [branch] in the isolated form; Boudelaa et al., 2019; Friedmann & Haddad-Hanna, 2012; Carreiras et al., 2012, 2013; Yakyup et al., 2015).

The simplest explanation would be that the mechanisms underlying the recognition of letters and words in the Arabic script are largely equivalent to those of the Latin script (see Okano et al., 2013, for a similar claim regarding Japanese kana syllabaries). For instance, it could be argued that, rather than featuring a layer of "shape-specific" detectors for lowercase and uppercase letters (Latin script; see Dehaene et al., 2005; Grainger et al., 2008), Arabic readers may acquire a layer of "shape-specific" detectors for the allographs of letter position (see Carreiras et al., 2013, 2014). Indeed, in letter-matching tasks with masked priming, when an Arabic target letter such as ع is used, the prime ـعـ (which is physically distinct but nominally identical) is just as effective as the prime ع (which is both physically and nominally identical) (Carreiras et al., 2012). This observation mirrors the results observed in the Latin script, where the lowercase prime letter e (which is nominally identical but physically different) is similarly effective as the uppercase prime letter E (which is both physically and nominally identical) in priming the uppercase target letter E (Kinoshita & Kaplan, 2008). Carreiras et al. (2013) also obtained this same behavioral pattern when the experiment was conducted with participants who had mastery of both scripts. Furthermore, they also recorded the event-related potentials of the participants during the task and found a strikingly similar time-course pattern of the priming effects in both Latin and Arabic scripts. Thus, there are similarities in how letter representations are encoded in both the Latin and Arabic scripts, indicating parallelisms between the two writing systems.

However, previous research has also revealed a remarkable dissociation in the effects of visual letter similarity in the first moments of word processing in the two scripts. In the masked priming technique, visual letter similarity effects have been repeatedly found in words with the Latin script (e.g., the target word *NEUTRAL* is responded to faster when the prime is visually similar, as in *nevtral*, than when the prime visually dissimilar prime, as in *neztral*; e.g., Marcet & Perea, 2017, 2018a, 2018b; see also Lally & Rastle, 2022, for evidence with the Reicher–Wheeler task). These effects appear to be absent for words written in Arabic. In experiments conducted with skilled adults and young readers, Perea et al. (2016, 2018) found that, in the case of the target word صحفية [journalist], the visually similar prime صحفية (created by changing one middle letter while maintaining the same base letter) was not more effective than the visually different prime صكفية (created by changing one middle letter to a different letter shape). Despite the null effect of visual letter similarity, a significant advantage was observed in the identity priming condition. A similar pattern was observed in a parallel manipulation using parafoveal previews during silent sentence reading in Arabic (AlJassmi et al., 2020).

The difference in the effects of visual letter similarity during the initial stages of word processing in Arabic and Latin scripts suggests the presence of cross-script variations. There are two primary explanations for this discrepancy. One possibility is that the origin of the visual similarity effects across writing systems lies at the level

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of individual letters. This idea arises from Wiley et al.'s (2016) observation that diacritics constitute the most salient feature of Arabic letters, causing readers to rapidly encode the dots and potentially reducing the influence of visual similarity effects when compared to parallel effects of visual similarity in Latin script. As shown above, the vast majority of Arabic letters share their base letter form with at least another one, the difference being the number or position of dots (e.g., the letters خ, ج and ح) readers must encode the dots (or lack thereof) accurately to encode letter identity. In this light, one might argue that letters that share their base form (e.g., خ and ح) may inhibit each other (i.e., lateral competition) as they compete for letter identification (see Pittrich & Schroeder, 2023, for a similar view regarding mirror letters like b and *d*). This scenario would suggest that, for Arabic readers, letters like خ and ج must be distinguished as separate letters very early in processing, reducing the potential effects of visual letter similarity in masked priming experiments.

The second possibility is that the dissociation does not occur during the encoding of individual letters but at higher processing levels (see Blais et al., 2009, for a dissociation of the role of visual features in isolated letters vs. words). This could be due to a variety of reasons. One explanation is that the patterns of letter connectivity in semicursive scripts, which convey a processing cost (see Alluhaybi & Witzel, 2020; Boudelaa et al., 2019; Yakup et al., 2015), might potentially reduce visual similarity effects in word recognition. A second potential factor is the phonological properties of Arabic. As short vowel diacritics are typically omitted – the exception is in a religious text or when learning the language, Arabic readers must rely on morpho-syntactic cues to discern the word's pronunciation (Abu-Rabia, 1997, 1998, 2001; Hermena et al., 2015, 2016). A third potential explanation is that, as Arabic is a Semitic language, it exhibits a rich morphological structure in which root and pattern letters intertwine to make up words. For instance, words like /'jak.tub/ يكتب [he writes], /'kaː.ti.ba/ كاتبة [female writer] and كتبتا/ka'tab.taː/ [the two females wrote] share the same three-consonant root (/k,t,b/ك ت ب), increasing the informational density of words without largely increasing their number of letters (see Abu-Rabia, 2002; Boudelaa & Marslen-Wilson, 2001, 2004, for more extensive discussion). This extra processing effort in morphological processing may obscure the (more perceptual) effects of visual letter similarity during word processing. Thus, the absence of visual letter similarity effects in Arabic could stem from visual and linguistic elements, including its unique inter-letter connectivity, or its phonological, and morphological properties. In this second scenario, one would expect a visual letter similarity effect at the individual letter level, which might be captured with letter identification tasks using masked priming. However, at later stages during word recognition processes, the impact of visual similarity would be reduced.

Accordingly, we designed two experiments to examine the plausibility of both scenarios: for individual letters, the first scenario would not predict an effect of visual letter similarity, whereas the second scenario would predict such an effect. To that end, we examined whether visual letter similarity effects can be obtained during the initial moments of letter recognition in Arabic script via masked priming. To directly compare with parallel visual similarity effects in the Latin script, we first present a brief overview of the scarce literature on these effects in letters with diacritics, which serve as the closest parallel to Arabic script in the Latin script. We then outline the rationale behind the two experiments.[2]

Using an alphabetic decision task ("Is the stimulus an existing letter?"; see Brosette et al., 2022, for the advantages of this task) in French, Chetail and Boursain (2019) found that the response times to a non-diacritical vowel (e.g., *A*) was remarkably similar the same when the prime was nominally identical to the target except for an added diacritic (e.g., *à*) and when the prime was a visually dissimilar consonant (−1 and 5 ms in Experiments 1A and 1B). In addition, the identity condition (*a-A*) produced faster responses than the visually similar (diacritic) condition (*à-A*; 20 ms in Experiment 1A and 18 ms in Experiment 1B, the latter being a replication). Perea et al. (2020) reexamined this issue in a masked priming alphabetic decision task in Spanish. They chose unrelated primes with the same consonant/vowel status and diacritic status as the visually similar primes. They found a visual similarity effect of similar magnitude for diacritical and non-diacritical target vowels (on average, *á-A* was responded to 11 ms faster than *ó-A*; *a-Á* was responded to 15 ms faster than *o-Á*). Notably, the advantage of the identity priming condition over the visually similar condition occurred for non-diacritical target letters (e.g., *a-A* faster than *á-A*) but not for diacritical letters (e.g., *á-Á* produced similar response times as *a-Á*). This perceptual asymmetry resembles that reported in visual search tasks in which removing a feature (e.g., finding *F* among an array of *E*'s) makes the item more similar than adding a feature (e.g., finding *E* among an array of *F*'s; Treisman, 1982). This asymmetric pattern is consistent with Norris and Kinoshita's (2012) noisy-channel model, which assumes that our cognitive system is equipped to complete the absent information that may be lost due to the uncertainties in perception – this explains why the prime *a* is effective for the diacritical target letter *Á*. However, once we do perceive these features, they strongly argue against their absence – this explains why the diacritical prime *á* is not highly effective for the non-diacritical target letter *A* (see Kinoshita et al., 2023, for parallel evidence with English readers who did not know orthographies with diacritics in a letter-matching task). To examine the generality of these effects, Marcet et al. (2022) conducted a parallel experiment in Catalan (i.e., another Romance language). Importantly, unlike Spanish, in which diacritics do not alter vowel sounds (i.e., *á* and *a* are pronounced /a/), Catalan has vowel reduction for non-stressed syllables and a complex grapheme-phoneme mapping for non-diacritical vowels (e.g., the letter *a* can be pronounced, depending on the word, as /a/ or /ɜ/), but a straightforward grapheme-phoneme mapping for diacritical vowels (e.g., *à*→/a/). Marcet et al. found an effect of visual similarity (13 ms across conditions) in Catalan. However, unlike Spanish, the advantage of the identity condition over the visually similar condition did not reflect a pattern of perceptual asymmetry: *à-À* produced faster responses than *a-À*, whereas *à-A* produced similar response times as *a-A*. Thus, leaving aside that language may modulate the pattern of perceptual asymmetries in letter identification; the main conclusion is that it is possible to obtain reliable visual similarity effects (visually dissimilar vs. visually similar primes) in masked priming experiments with Latin letters. Furthermore, at

[2]The presence of diacritics in Latin-based alphabets is more the norm than the exception: all countries in Europe have languages with diacritical letters, including the United Kingdom (e.g., Welsh and Scottish Gaelic, but not English).

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least in some circumstances, visually similar primes can be as effective as identity primes.

In the present study, we examine whether visual similarity effects occur in the early phases of letter recognition in Arabic. To that end, we conducted two masked priming experiments with Arabic letters. (The rationale for Experiment 2 will be discussed in Section 5.) Experiment 1 used an alphabetic decision task with the same design as Perea et al.'s (2020) experiment. The difference was that instead of selecting five Spanish vowels with and without diacritics (e.g., *A* and *Á*; *E* and *É*; *I* and *Í*, *O* and *Ó*, *U* and *Ú*), we chose five pairs of Arabic letters that shared their base letters and only differed in the presence/absence of a dot: ع /ʕ/ and غ /ɣ/, ط /tˤ/ and ظ /ðˤ/, ص /sˤ/ and ض /dˤ/, د /d/ and ذ /ð/, ح /ħ/ and خ /x/. Each target letter (e.g., ح) could be preceded by a visually similar prime with the same base letterform differing in the diacritics (visually similar condition; e.g., خ – ح), or by a control prime which shared the same dot pattern as the visually similar prime (visually dissimilar condition; e.g., ظ - ح). This design ensured that any differences between the visually similar and visually dissimilar could not be attributed to the dots' presence or absence. Similar to Perea et al.'s (2020) experiment, we also included an identity priming condition (e.g., ح) as it would provide an upper criterion for how effective the visually similar primes are. The two contrasts were: (1) visually similar prime versus visually dissimilar prime (i.e., the effect of visual letter similarity) and (2) identity prime versus visually similar prime (i.e., a measure of the effectiveness of the visually similar prime). We chose the isolated form of Arabic letters not only because it is typically taught first to children and is the standard for keyboards but also because the allographs indicating initial, middle or final position necessarily imply the contextual presence of other letters.[3] For the non-letters, we chose five letters from the Brussels Artificial Character Sets (Vidal et al., 2017) that had a resemblance to Arabic letters – these letters would be presented with and without dots (see Table 2). Primes were written in a different font that was smaller in size (Times New Roman) than the targets (Kawkab Mono) so that the pattern mask effectively covered the primes (see Figure 1 for illustration).

In sum, the main aim of Experiment 1 was to investigate the effects of visual letter similarity at the individual letter level in a masked priming alphabetic decision task. If models of letter identification in Arabic parallel those proposed in the Latin script (e.g., Dehaene et al., 2005; Grainger et al., 2008), we would expect to observe an advantage of the visually similar condition over the control (e.g., خ – ح faster than ظ – ح). This outcome would suggest that: (1) models of letter recognition in the Latin script could be generalized to Arabic and (2) the lack of visual letter similarity with Arabic words would be due to factors that surpass the letter level. Alternatively, if Arabic readers can quickly encode the presence/absence of dots in letters, one would expect a negligible visual similarity effect in a masked priming task. This outcome would parallel previously reported with Arabic words (Perea et al., 2016, 2018). Finally, the present experiment also tests whether the ideas proposed by the noisy-channel model (Norris & Kinoshita,

[3]In the Aralex database, 58% of the top 100 frequent Arabic words use the isolated letter form (Boudelaa & Marslen-Wilson, 2010). Boudelaa et al. (2020) found that the isolated form makes up 31% of letters with a 0.4 occurrence rate; the beginning form is 20% with a 0.9 rate; the medial form is 27% with a 0.9 rate, and the final form is 22% with a 1.4 rate.

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Table 2. Representation of the prime–target pairs in Experiment 1

Type of stimulus							
Letter				Non-Letter			
Targets	Type of prime			Targets	Type of prime		
	identity	Visually Similar	Visually Dissimilar		identity	Visually Similar	Visually Dissimilar
ع	ع	غ	خ	[illegible]	ع	غ	خ
ط	ط	ظ	ض	[illegible]	ط	ظ	ض
ص	ص	ض	ذ	[illegible]	ص	ض	ذ
د	د	ذ	غ	[illegible]	د	ذ	غ
ح	ح	خ	ظ	[illegible]	ح	خ	ظ
غ	غ	ع	ح	[illegible]	غ	ع	ح
ظ	ظ	ط	ص	[illegible]	ظ	ط	ص
ض	ض	ص	د	[illegible]	ض	ص	د
ذ	ذ	د	ع	[illegible]	ذ	د	ع
خ	خ	ح	ط	[illegible]	خ	ح	ط

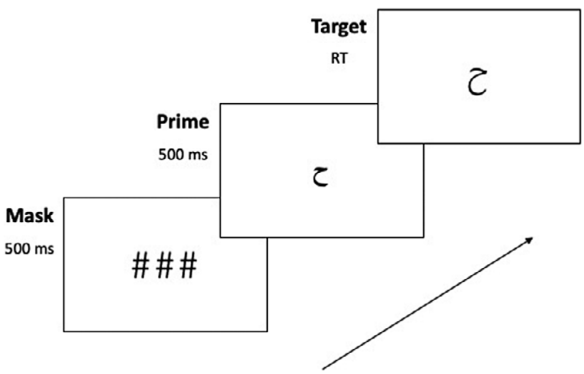

Figure 1. Depiction of the masked priming task: A forward mask (###) is presented for 500 ms, followed by a prime that is presented for 50 and is immediately replaced by the target letter until the participant's response.

2012; see also Kinoshita et al., 2021). As indicated earlier, this model proposes that the addition of a feature in an item would make the percept less similar to the original than the omission of a feature. If this is so, the effects of visual similarity would be greater for non-diacritical targets (e.g., خ- ح) than for diacritical targets (e.g., ح – خ). This is because the visually similar prime (e.g., خ) for non-diacritical targets (e.g., ح) includes an additional feature absent from the target, while for diacritical targets, the prime (e.g., ح) includes all the features of the target, making it more similar (e.g., خ). In line with this, both diacritical and non-diacritical visually similar primes (e.g., ح – خ or خ – ح) are likely to be processed faster than those in the control condition (e.g., ح – ظ or خ – ط). This is due to the greater feature overlap that visually similar primes share with their corresponding targets, in contrast to controls.

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2. Experiment 1 (alphabetic decision task)

2.1. Method

2.1.1. Participants

Forty-eight university students (20 males, mean age = 20 years, *SD* = 2 years), all native speakers of Arabic, took part voluntarily in the experiment. This sample size allowed us to have 3,840 observations in each priming condition, which is above the guidelines given by Brysbaert and Stevens (2018). The two experiments reported in this paper received ethical approval from the Ethics Committee of Zayed University and followed the principles of the Declaration of Helsinki.

2.1.2. Materials

The target letters were the five pairs of Arabic letters with the same base letter. The only difference was that five letters had dots on top (غ, ظ, ض, ذ, خ), and the other five letters did not have dots (ع, ط, ص, د, ح). For each target letter, we created three types of primes: 1) identical to the target (identity condition; e.g., ح – ح or خ – خ); 2) a visually similar letter that was identical to the target except for the addition/removal of the accent mark while keeping the same base letter (visually similar condition; e.g., خ – ح or ح – خ; the mean visual similarity rating on a 1–7 Likert scale was 5.8 [range: 5.8–5.9] in the Arabic matrix collected by Boudelaa et al., 2020) and 3) a different letter with/without an accent mark in accordance with the visually similar prime (visually dissimilar condition; e.g., ظ – ح or ط – خ; the mean visual similarity rating was 2.3 [range: 1.3–3.9] in the Boudelaa et al., 2020, matrix). To add a dot to the non-artificial letters, we used TypeLight 3.2 software (https://www.cr8software.net/typelight.html). Each non-letter target was preceded by a non-accented or an accented letter in the same manner as the letter targets (see Table 2, for a depiction of the conditions). As in Perea et al. (2020), we repeated the cycles presented in Table 2 8 times to create a list of 480 experimental trials (240 letters [80 in each priming condition]) and 240 non-letters. Sixteen practice trials preceded the experimental trials.

2.1.3. Apparatus

Stimuli were presented on a Gamma-corrected video monitor with a screen resolution of 1920 × 1080 pixels. The experiment was controlled by Experiment Builder (SR Research Ltd., Ontario, Canada) and was connected to a Silverstone computer. Each stimulus was viewed from a distance of 60 cm. All stimuli were presented in the center of the screen and were all black on a white background.

2.1.4. Procedure

During testing, participants were in a quiet room free from disturbances. They were instructed to decide, as quickly and accurately as possible, whether the stimulus on the computer screen was a letter or not. On each trial, the following display sequence appeared: 500 ms a pattern mask (###), 50 ms a prime letter, a target stimulus, which remained on the screen until the participant either pressed the “green” (yes) or the “red” (no) buttons, or until a 2-s deadline was reached. Participants responded using a VPixx button box interfaced with the computer. The trial was categorized as an error if no response was within the 2-s deadline. The session took 15–18 min.

Table 3. Mean accuracy rates (in percentages) and response times (in ms) for accented and non-accented letter for each of the three priming conditions (identity, visually similar, visually dissimilar) in Experiment 1

	Accented letter		Non-accented letter	
	Accuracy	Response time	Accuracy	Response time
Identity	0.963	503	0.949	511
Visually similar	0.957	507	0.959	517
Visually dissimilar	0.955	518	0.956	530

3. Results

For the latency analyses, we removed the error responses (4.3% of trials) and the very short response times (less than 200 ms; 0.2% of trials) – note that no RTs exceeded the 2-s deadline. Table 3 presents the mean accuracy rates and response times in each experimental condition. We focused on the letter trials only.

To conduct the inferential analyses, we created Bayesian linear mixed-effects models on the correct response times and the accuracy using the brms package (Bürkner, 2018) in the R environment (R Core Team, 2021). The fixed factors were type of letter (diacritical, non-diacritical, coded as 0.5 and −0.5) and prime–target similarity (identity, visually similar, visually dissimilar). In the analyses presented here, the pairs of letters (e.g., خ and ح) were treated as different items (i.e., they are different letters in Arabic) rather than variations of the same base letter form. As in Perea et al.'s (2020) experiment, the visually similar condition acted as a reference for prime–target similarity, thus allowing us to examine the difference between the visually dissimilar versus visually similar conditions (i.e., the visual letter similarity effect) and the difference between the visually similar condition and the identity condition. We chose the models with the maximal random-effect structure (see Barr et al., 2013):

Dependent variable ~ type of letter * prime–target similarity + (1 + type of letter * prime–target similarity |subject) + (1 + prime–target similarity |item).

The latency analyses were modeled with the exGaussian distribution due to the positive skew of response times. The accuracy data were modeled with the Bernoulli distribution due to the binary nature of the responses (correct = 1, incorrect = 0). For each model, we conducted 5,000 iterations (1,000 as a warm-up) using four chains. All models successfully converged (R-hats = 1.00 in all cases). The output of Bayesian linear mixed-effects models includes an estimation of each parameter, its standard deviation, and the 95% credibility interval (CrI). This interval is the central portion of the posterior distribution that contains 95% of the values. If the CrI does not encompass a 0 (i.e., strictly positive or negative), it would be interpreted as evidence of an effect (see Cutter et al., 2022; Perea et al., 2022). The posterior distributions for each parameter in the RT analysis are presented in Figure 2.

3.1. Response times

We found a 12-ms advantage of the visually similar condition over the visually dissimilar condition, $b = 0.07$, $SE = 0.02$, 95% CrI(0.03, 0.11), which was similar for diacritical and non-diacritical letters (interaction: $b = 0.01$, $SE = 0.04$, 95% CrI(−0.07, 0.08)). In addition, we found a 5-ms advantage of the identity condition over the

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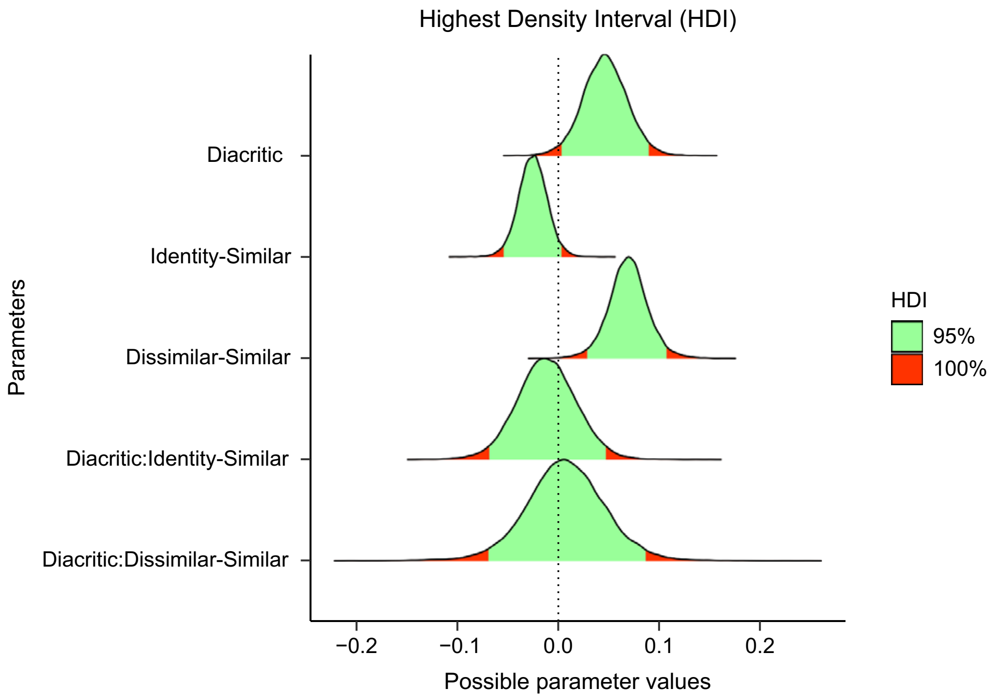

Figure 2. Posterior distributions of each parameter for the Bayesian linear mixed-effects model on response times in Experiment 1. The green area represents the 95% credible interval for each parameter.

visually similar condition, $b = -0.03$, $SE = 0.01$, 95% CrI(−0.05, 0.00) that was also similar for accented and non-accented letters (interaction: $b = -0.01$, $SE = 0.03$, 95% CrI(−0.07, 0.05); see Figure 2).

3.2. Accuracy

There were no signs of any effects – note that accuracy was very high and comparable in all conditions (>95%).

4. Discussion

The present experiment, using a task that relies on the readers' knowledge of the letters (i.e., "is the stimulus a real letter?"), revealed an effect of visual letter similarity in the first moments of letter encoding in the Arabic script. Specifically, visually similar letter primes were more effective than visually dissimilar letter primes.[4] This finding extends to Arabic previous evidence reported with individual letters in the Latin script (e.g., Marcet et al., 2021; Perea et al., 2020). Thus, the apparent differences in visual letter similarity between Arabic and Latin scripts in masked priming experiments appear to occur at higher processing levels than the letter level. Notably, in the present task, the effect of visual similarity was remarkably similar for diacritical and non-diacritical letters (i.e., there were no signs of a perceptual asymmetry pattern; see Table 3).

To examine the generality of the current findings, we conducted a parallel experiment using the same-different task, which is a more perceptually based task. Indeed, as mentioned earlier, previous research has shown a perceptual asymmetry pattern with Latin letters (O – Q faster than Q – O) and Japanese letters (カ - ガ faster than ガ - カ) with this task (Kinoshita et al., 2021, 2023). The idea is that, in a noisy-channel model, the absence of a feature is less damaging than adding a feature (Kinoshita et al., 2021). In this task, the participant has to decide whether a probe (e.g., the letter *T* or the letter *C*), presented for 500 ms, is the same as a target stimulus (e.g., the letter *T*). In the masked prime version of the task, target presentation is preceded by a forwardly masked prime, so it is possible to examine the relationship between primes and targets. For diacritical Japanese katakana letters, Kinoshita et al. (2021) found a strong visual similarity effect (i.e., カ - ガ faster than the unrelated prime バ - ガ; a 93-ms difference) – this was accompanied by a small, 6-ms advantage of the identity condition (e.g., ガ - ガ) over the omitted-diacritic condition (i.e., カ - ガ). For non-diacritical katakana letters, Kinoshita et al. (2021) found a 40-ms visual similarity effect (i.e., ガ - カ faster than the control priming condition サ - カ) – this was accompanied by a 32-ms advantage of the identity condition (e.g., カ - カ) over the diacritic condition (ガ - カ) (see also Kinoshita et al., 2023, for similar evidence with diacritical vs. non-diacritical vowels in English readers).

[4]We conducted a post hoc analyses computing the visual similarity effect was observed in cases where unrelated primes exhibited an extremely low similarity (6 pairs, e.g., ص ذ; similarity range: 1.3–1.5 out of 7) or a moderately low level of similarity (4 pairs, e.g., ح غ; similarity range: 3.2–3.9 out of 7). The resulting magnitudes of the visual similarity priming effect were 13 and 10 ms, respectively. Thus, the magnitude of the visual similarity effect was only barely shaped by this particular element.

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In sum, the main goal of Experiment 2 was to examine the presence of an effect of visual letter similarity using a perceptually based task. We employed the same controls for the visually similar primes as in Experiment 1. Another goal of this experiment was to examine whether this task was more prone to the appearance of perceptual asymmetry in the magnitude of the visual similarity effects. If this is so, visually similar primes created by removing the diacritical mark from a diacritical target letter (e.g., show خ – ح) would produce a larger visual similarity effect relative to their corresponding unrelated controls (e.g., ط – خ), than those visually similar primes created by adding a diacritical mark to a non-diacritical target letter (e.g., خ – ح when compared to ظ – ح).

5. Experiment 2 (letter-matching task)

The design of Experiment 2 was similar to that of Kinoshita et al. (2021). We used the letter-matching task, where participants were instructed to decide whether a single target letter matched a probe letter (see Figure 3 for illustration). As in Experiment 1, two types of target letters were used (diacritical and non-diacritical). Each target letter was preceded by a briefly presented prime letter, one of three primes (identity, visually similar, visually dissimilar). The sole difference in the present experiment, akin to Experiment 1 and the study by Perea et al. (2020), was that visually dissimilar primes were matched to visually similar primes in terms of the presence or absence of dots.

5.1. Method

5.1.1. Participants

Forty-eight university students (all females, mean age = 20 years, *SD* = 2 years) from the same population as in Experiment 1 participated voluntarily. As in Experiment 1, this sample size allowed us to have 3840 observations per priming condition.

Materials and design

We used the same five target letters as in Experiment 1 (with dots: خ, ذ, ض, ض, ظ, غ and without dots ح, د, ص, ط, ع). Each target letter was paired with three types of

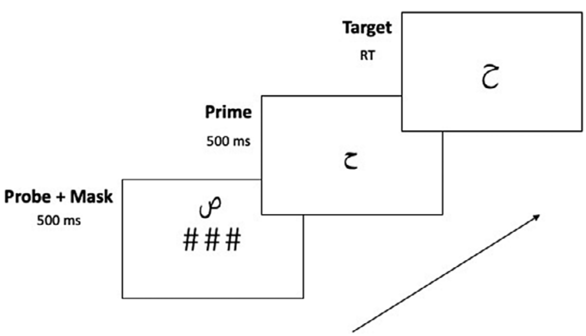

Figure 3. Depiction of the letter-matching task: A probe is presented for 500 ms, together with a forward mask (#####), followed by a prime that is presented for 50 and is immediately replaced by the target letter until the participant's response.

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Table 4. Depiction of the probe-prime–target pairs in Experiment 2

Type of trial									
Same					Different				
Probe	Targets	Type of prime			Probe	Targets	Type of prime		
		identity	Visually Similar	Visually Dissimilar			identity	Visually Similar	Visually Dissimilar
ع	ع	ع	غ	خ	د	ع	ع	غ	خ
ط	ط	ط	ظ	ض	ح	ط	ط	ظ	ض
ص	ص	ص	ض	ذ	ع	ص	ص	ض	ذ
د	د	د	ذ	غ	ط	د	د	ذ	غ
ح	ح	ح	خ	ظ	ص	ح	ح	خ	ظ
غ	غ	غ	ع	ح	ذ	غ	غ	ع	ح
ظ	ظ	ظ	ط	ص	خ	ظ	ظ	ط	ص
ض	ض	ض	ص	د	غ	ض	ض	ص	د
ذ	ذ	ذ	د	ع	ظ	ذ	ذ	د	ع
خ	خ	خ	ح	ط	ض	خ	خ	ح	ط

primes: 1) identical to the target (identity condition; e.g., ح – ح or خ – خ); 2) identical to the target except for the addition/removal of the accent mark while keeping the same base letter (visually similar condition; e.g., خ – ح or ح – خ); and 3) a different letter with/without an accent mark in accordance with the visually similar prime (visually dissimilar condition; e.g., ظ – ح or ط – خ). Each prime–target pair was presented 16 times in the "same" response condition (5 targets × 3 prime conditions × 16 times = 240) and 16 times in the "different" response condition (5 targets × 3 prime conditions × 16 times = 240), resulting in 480 experimental trials in total preceded by 16 practice trials. In the "same" condition, the probe matched the target letter; in the "different" condition, the probe and the target were different (e.g., probe: ص, target: ح; see Table 4).

5.1.2. Apparatus and procedure

The device and the general procedure were similar to those in Experiment 1. Participants were told that two letters would be presented in succession and that their task was to decide whether the two were the same as quickly and accurately as possible. On each trial, a probe will be presented above a pattern mask (i.e., a series of #'s) for 500 ms, followed by a prime letter presented for 50 ms, then a target stimulus which remained on the computer screen until a response was made or until timeout after a 2-s. Participants pressed the green button to indicate that the two letters were the same and the red button to indicate that they were different. The probe and target letters were presented in Kawkab Mono font, and the prime letters were presented in Times New Roman font, which was smaller to avoid physical continuity (see Figure 3). As in Experiment 1, each session took approximately 15–18 min.

6. Results and Discussion

As in Experiment 1, incorrect responses (11.4% of trials) and RTs shorter than 200 ms (0.7% of trials) were removed from the latency analyses. Only the "same" trials from the letter-matching task were analyzed, as usual – for the interested readers, the

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Table 5. Mean accuracy rates (in percentages) and response times (in ms) for accented and non-accented letters for each of the three priming conditions (identity, visually similar, visually dissimilar) in Experiment 2

	Accented letter		Non-accented letter	
	Accuracy	Response time	Accuracy	Response time
Identity	0.881	514	0.925	481
Visually similar	0.874	517	0.898	517
Visually dissimilar	0.850	548	0.887	546

differences across priming conditions for "different" trials were minimal. The mean accuracy rates and response times in each condition are displayed in Table 5. The inferential analyses were parallel to Experiment 1 – again, all models converged adequately (R-hat = 1.00 in all estimates). Figure 4 presents a plot with the posterior distributions for each effect in the RT analysis.

6.1. Response times

Concerning the visual similarity effect, responses for target letters were faster when preceded by a visually similar prime than when preceded by a visually dissimilar prime, $b = 0.14$, $SE = 0.03$, 95% CrI [0.08, 0.20] (a 30-ms advantage). This advantage was roughly the same for accented and non-accented letters (interaction: $b = -0.02$, $SE = 0.06$, 95% CrI [−0.14, 0.10]).

In addition, responses to letters were faster when preceded by an identity prime than when preceded by a visually similar prime, $b = -0.09$, $SE = 0.03$, 95% CrI [−0.14, −0.03] (a 20-ms advantage). Critically, the magnitude of this effect was greater for non-diacritical than for diacritical letters (interaction: $b = 0.12$, $SE = 0.06$, 95% CrI [0.02, 0.24], 36 vs. 3 ms, respectively). Thus, in comparison to the corresponding identity condition, the recognition of diacritical letters is more greatly facilitated by visually similar non-diacritical letters than vice versa (i.e., perceptual asymmetry; see Figure 4 for a plot with the posterior distributions).

6.2. Accuracy

The analyses on the accuracy data only showed higher accuracy to the target letters when preceded by an identity prime than when preceded by a visually similar prime, $b = 0.20$, $SE = 0.09$, 95% CrI (0.03, 0.38).

Thus, the present masked prime letter-matching task showed that visually similar primes were more effective than visually dissimilar primes at activating a target letter in Arabic (خ – ح faster than ظ – ح). This pattern held true regardless of whether or not the target item contained dots, thereby extending the findings of Experiment 1 to another task.[5] The only differences with respect to Experiment 1, which we will

[5]As in Experiment 1, we conducted a similar post hoc analyses for the unrelated pairs with an extremely low similarity or a moderately low level of similarity. While the effect for the latter primes was large (20 ms), it was even greater for the pairs with an extremely low similarity value (37 ms). While this difference must be taken with caution (i.e., it was not significant), it suggests that the letter-matching task is particularly sensitive to subtle changes in visual similarity.

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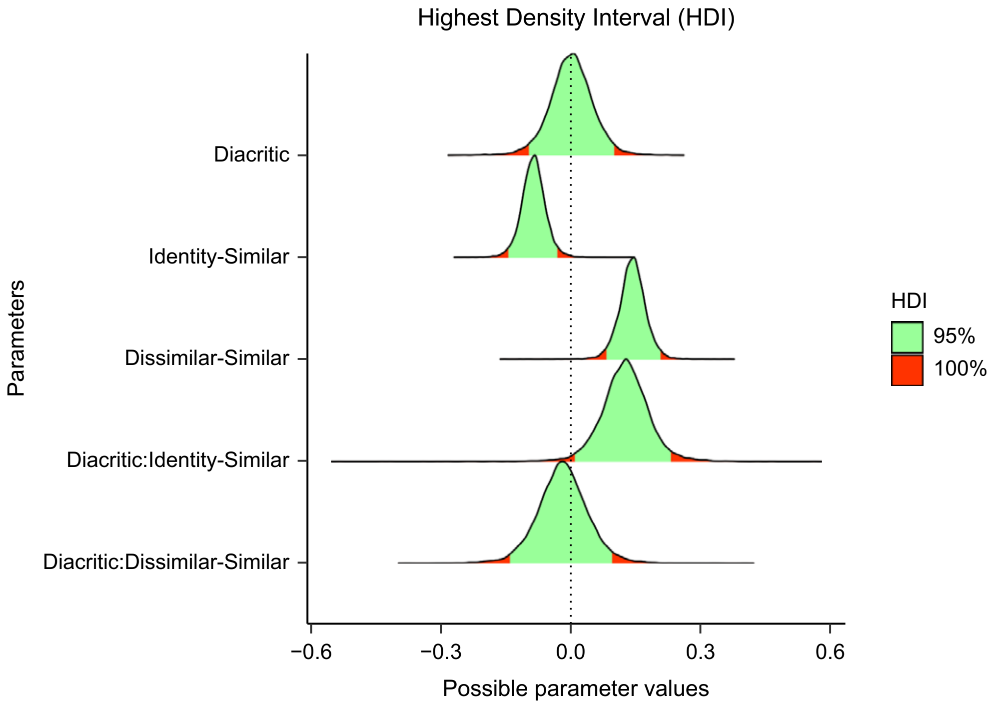

Figure 4. The posterior distributions of each parameter for the Bayesian linear mixed-effects model on response times in Experiment 2. The green area represents the 95% credible interval for each parameter.

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develop in the General discussion section, were: (1) the comparison between identity primes and visually similar primes: visually similar primes were as effective as identity primes for diacritical letters (خ – خ = ح – خ), but not for non-diacritical letters (ح – ح faster than خ – ح), and (2) we found a pattern of asymmetric priming when comparing the identity condition and the visually similar condition (ح– خ faster than خ – ح), replicating recent research with the letter matching technique with this task (e.g., Kinoshita et al., 2021, 2023).

7. General discussion

In this article, we explore whether the processing of the visual elements in individual letters exhibits universality across diverse scripts. Specifically, we pose the question: can visual letter similarity effects, consistently observed in Latin script studies, also be observed in Arabic? We selected Arabic for this study because, unlike the Roman script, previous research on word processing in Arabic has consistently failed to reveal visual letter similarity effects (e.g., AlJassmi et al., 2020; Perea et al., 2016, 2018).

To answer this question, we conducted two masked priming experiments examining the effects of visual letter similarity on Arabic letters. The results of both the alphabetic decision task (Experiment 1) and the letter-matching task (Experiment 2) showed a processing advantage of a target letter when preceded by a visually similar letter prime compared to when preceded by a visually dissimilar letter prime (12 ms in Experiment 1 and 30 ms in Experiment 2). Interestingly, the magnitude of this advantage was remarkably similar for diacritical and non-diacritical Arabic letters, with a greater size in the letter-matching task.

Therefore, these results strongly suggest that, at the letter level, the principles of early perceptual ambiguity that govern letter identification in the Latin script may also apply to the Arabic script. This reinforces the idea that the mechanisms underlying letter recognition in these two scripts are qualitatively the same (see Carreiras et al., 2013; see also Okano et al., 2013, for a similar observation on Japanese syllabaries).

We also examined whether visually similar primes could be as effective as identity primes. In the alphabetic decision task (Experiment 1), the identity primes were only slightly more effective than the visually similar primes (a 5-ms difference), regardless of whether the target letter was accented or not (the difference was 4 and 6 ms for non-accented and accented letter targets, respectively). In the letter-matching task (Experiment 2), the visually similar primes were as effective as the identity primes (a 3-ms difference) for diacritical letter targets. In contrast, for non-diacritical targets, the visually similar primes were much less effective than the identity primes (a 36-ms difference), thus revealing some perceptual asymmetry (see Kinoshita et al., 2021, 2023 for a similar pattern). The dissociation observed between the letter-matching task and the letter-based task strongly indicates that a letter-matching task may be more sensitive to detecting patterns of perceptual asymmetry.

Despite the task-dependent modulation of identity versus visually similar priming conditions, the central finding of the present experiments is that reliable effects of visual letter similarity can be obtained in Arabic letter identification tasks. Crucially, this finding offers valuable insights into the localization of this effect within the Arabic script: it indicates that models of letter perception in the Arabic script are comparable to those in the Latin script, thus corroborating Carreiras et al.'s (2012, 2013) findings with allographs in a letter-matching masked priming task (e.g., ـعـ - ع = زـز). The next question that arises is why these visual similarity effects are not observed during word recognition in masked priming paradigms (Perea et al., 2016, 2018) and sentence reading parafoveal preview paradigms (AlJassmi et al., 2020).

One possible explanation for this discrepancy is that the initial stages of letter encoding may be universal, but the process of visual word recognition may differ between the Latin and Arabic scripts, possibly because Arabic words lack vowel information and undergo strict morphological processing at the lexical level, which could make the effects of visual letter similarity less noticeable than in the Latin script. The idea is that there would be a dense perceptual space in Arabic words, which would decrease masked priming effects (see Forster & Taft, 1994, for evidence of how dense lexical space diminishes masked priming effects). It should be noted that visual similarity effects in the Latin script are transient and disappear at later processing stages, as reported in previous studies (e.g., see Gutiérrez-Sigut et al., 2019, using electrophysiological measures; see also AlJassmi et al., 2022, for evidence in sentence reading).

One significant aspect to consider is the intricate patterns of letter connectivity within the Arabic script, particularly in semicursive forms. Existing research has indicated that these patterns introduce a processing cost (e.g., see Alluhaybi & Witzel, 2020; Boudelaa et al., 2019; Yakup et al., 2015). The increased connectivity might potentially obscure or reduce the impact of visual similarity effects in word recognition. The idea is that the perceptual processes that occur at earlier stages during the encoding of individual letters may be affected differently when compared to later stages of word recognition, where the influence of visual similarity effects could be diminished (i.e., letter identities would be encoded; see Gutierrez-Sigut et al., 2019).

In addition, the phonological characteristics of Arabic may also play an important role, as readers often rely on morpho-syntactic cues for word pronunciation (Abu-Rabia, 1997, 1998, 2001; Hermena et al., 2015, 2016). This reliance on morpho-syntactic Arabic pronunciation cues could potentially alter or affect the visual letter similarity effects at levels beyond the individual letter. Specifically, when readers use these cues to determine word pronunciation, it may divert their attention away from the more perceptual aspects of visual letter similarity, potentially explaining the absence of these effects at the word level.

Another potential factor to consider is the Semitic morphology of Arabic, which may significantly contribute to the lack of visual letter similarity effects beyond the level of individual letters (Abu-Rabia, 2002; Boudelaa & Marslen-Wilson, 2001, 2004). The intricate interplay of root and pattern letters in Arabic words can lead to multifaceted morphological structures that require heightened cognitive effort to process effectively. Indeed, it has often been claimed that one could not obtain masked form priming in Arabic (see Perea et al., 2014, for discussion), which would limit the strength of how effective a visually similar prime is (i.e., it would be a form-related prime). As a result, this increased demand for morphological processing may potentially overshadow or diminish the perceptual effects of visual letter similarity during word recognition.

Thus, the visual letter similarity effects that occur at the level of individual letters, as shown in the present experiments, might become less noticeable as we progress to later stages of word recognition. This possible trend could be due to the intricate way

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Arabic letters connect, their specific phonological characteristics, and their rich morphological structure. To pinpoint these specific mechanisms, further research is needed to thoroughly explore visual word recognition in Arabic and potentially in other scripts with similar characteristics. Another related avenue that research could further elucidate the intricacies of single-letter and word recognition in Arabic is by investigating the temporal dynamics of these effects through event-related potentials, as well as the neural pathways involved (e.g., using neuroimaging techniques).

In conclusion, the present experiments demonstrated the presence of a visual similarity effect during the early stages of letter encoding in Arabic script. We found an advantage in the identification of target letters when they were preceded by a visually similar prime compared to a visually dissimilar prime. This effect was consistent for both diacritical and non-diacritical letters (e.g., خ – ح faster than ظ – ح; ح – خ faster than ط – خ). Notably, we found an asymmetrical pattern, restricted to the more perceptual letter-matching task when comparing identity versus visually similar primes (i.e., a greater difference effect when the dot was removed in the visually similar prime, as in ح – خ than خ – ح), which is consistent with Norris and Kinoshita's (2012) noisy-channel model. Thus, our findings highlight similarities and disparities in how letters are encoded between the Arabic and Latin scripts, providing a unique opportunity for further investigation into the nuances of letter and word recognition in both writing systems.

Supplementary material. The supplementary material for this article can be found at http://doi.org/10.1017/langcog.2024.20.

Data availability statement. The data, script and output of the experiments are available at: https://osf.io/ktga2/?view_only=3f17c57553944d63b929c9d05cd70e87.

References

Abu-Rabia, S. (1997). Reading in Arabic orthography: The effect of vowels and context on reading accuracy of poor and skilled native Arabic readers in reading paragraphs, sentences, and isolated words. *Journal of Psycholinguistic Research*, 26, 465–482. https://doi.org/10.1023/A:1025034220924

Abu-Rabia, S. (1998). Reading Arabic texts: Effects of text type, reader type, and vowelization. *Reading and Writing*, 10, 105–119. https://doi.org/10.1023/A:1007906222227

Abu-Rabia, S. (2001). The role of vowels in reading Semitic scripts: Data from Arabic and Hebrew. *Reading and Writing*, 14, 39–59. https://doi.org/10.1023/A:1008147606320

Abu–Rabia, S. (2002). Reading in a root–based–morphology language: The case of Arabic. *Journal of Research in Reading*, 25, 299–309.

AlJassmi, M. A., Hermena, E. W., & Paterson, K. B. (2021). Eye movements in Arabic reading. In D. Ntelitheos and T. Leung (Eds.), *Experimental Arabic Linguistics*, 10, 85–108. https://doi.org/10.1075/sal.10.03alj

AlJassmi, M. A., McGowan, V. A., White, S. J., & Paterson, K. B. (2020, November). *Foveal and parafoveal processing of letter information in Arabic reading* [Poster presentation]. Virtual Psychonomics meeting.

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. https://doi.org/10.3758/s13414-021-02375-1.

Alluhaybi, I., & Witzel, J. (2020). Letter connectedness and Arabic visual word recognition. *Quarterly Journal of Experimental Psychology*, 73, 1660–1674. https://doi.org/10.1177/1747021820926155

Asaad, H., & Eviatar, Z. (2014). Learning to read in Arabic: The long and winding road. *Reading and Writing*, 27, 649–664. https://doi.org/10.1007/s11145-013-9469-9

Barr, D. J., Levy, R., Scheepers, C., & Tily, H. J. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of Memory and Language*, 68, 255–278. https://doi.org/10.1016/j.jml.2012.11.001

Benyhe, A., Labusch, M., & Perea, M. (2023). Just a mark: Diacritic function does not play a role in the early stages of visual word recognition. *Psychonomic Bulletin & Review*. https://doi.org/10.3758/s13423-022-02244-4

Blais, C., Fiset, D., Jolicoeur, P., Arguin, M., Bub, D. N., & Gosselin, F. (2009). Reading between eye saccades. *PLoS ONE*, 4(7), e6448. https://doi.org/10.1371/journal.pone.0006448

Boudelaa, S., & Marslen-Wilson, W. D. (2001). Morphological units in the Arabic mental lexicon. *Cognition*, 81,65–92. https://doi.org/10.1016/S0010-0277(01)00119-6

Boudelaa, S., & Marslen-Wilson, W. D. (2004). Allomorphic variation in Arabic: Implications for lexical processing and representation. *Brain and Language*, 90, 106–116. https://doi.org/10.1016/S0093-934X(03)00424-3

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

Boudelaa, S., Norris, D., Mahfoudhi, A., & Kinoshita, S. (2019). Transposed letter priming effects and allographic variation in Arabic: Insights from lexical decision and the same–different task. *Journal of Experimental Psychology: Human Perception and Performance*, 45, 729–757. https://doi.org/10.1037/xhp0000621

Boudelaa, S., Perea, M., & Carreiras, M. (2020). Matrices of the frequency and similarity of Arabic letters and allographs. *Behavior Research Methods*, 52, 1893–1905. https://doi.org/10.3758/s13428-020-01353-z

Bürkner, P.-C. (2018). Advanced Bayesian multilevel modeling with the R package brms. *The R Journal*, 10, 395–411. https://doi.org/10.32614/RJ-2018-017

Brossette, B., Grainger, J., Lété, B., & Dufau, S. (2022). On the relations between letter, word, and sentence-level processing during reading. *Scientific Reports*, 12(1), 17735. https://doi.org/10.1038/s41598-022-22587-1

Brysbaert, M., & Stevens, M. (2018). Power analysis and effect size in mixed effects models: A tutorial. *Journal of Cognition*, 1(9), 1–20. https://doi.org/10.5334/joc.10

Carreiras, M., Armstrong, B. C., Perea, M., & Frost, R. (2014). The what, when, where, and how of visual word recognition. *Trends in cognitive sciences*, 18(2), 90–98.

Carreiras, M., Perea, M., & Abu Mallouh, R. (2012). Priming of abstract letter representations may be universal: The case of Arabic. *Psychonomic Bulletin and Review*, 19, 685–690. https://doi.org/10.3758/s13423-012-0260-8

Carreiras, M., Perea, M., Gil-López, C., Abu Mallouh, R., & Salillas, E. (2013). Neural correlates of visual vs. abstract letter processing in Roman and Arabic scripts. *Journal of Cognitive Neuroscience*, 25, 1975–1985. https://doi.org/10.1162/jocn_a_00438

Chetail, F., & Boursain, E. (2019). Shared or separated representations for letters with diacritics? *Psychonomic Bulletin & Review*, 26, 347–352. https://doi.org/10.3758/s13423-018-1503-0

Cutter, M. G., Paterson, K. B., & Filik, R. (2022). Online representations of non-canonical sentences are more than good-enough. *Quarterly Journal of Experimental Psychology*, 75, 30–42. https://doi.org/10.1177/17470218211032043

Dehaene, S., & Cohen, L. (2007). The role of visual similarity, feedforward, feedback and lateral pathways in reading. *Trends in Cognitive Sciences*, 11, 456–457. https://doi.org/10.1016/j.tics.2007.08.009

Dehaene, S., Cohen, L., Sigman, M., & Vinckier, F. (2005). The neural code for written words: a proposal. *Trends in Cognitive Sciences*, 9, 335–341. https://doi.org/10.1016/j.tics.2005.05.004

Friedmann, N., & Haddad-Hanna, M. (2012). Letter position dyslexia in Arabic: From form to position. *Behavioural Neurology*, 25, 193–203. https://doi.org/10.1155/2012/296974

Forster, K. I., & Taft, M. (1994). Bodies, antibodies, and neighborhood-density effects in masked form priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 20, 844–863. https://doi.org/10.1037/0278-7393.20.4.844

Grainger, J. (2018). Orthographic processing: A 'mid-level' vision of reading. *Quarterly Journal of Experimental Psychology*, 71, 335–359. https://doi.org/10.1080/17470218.2017.1314515

Grainger, J., Rey, A., & Dufau, S. (2008). Letter perception: From pixels to pandemoniums. *Trends in Cognitive Sciences*, 12, 381–387. https://doi.org/10.1016/j.tics.2008.06.006

Gutiérrez-Sigut, E., Marcet, A., & Perea, M. (2019). Tracking the time course of letter visual-similarity effects during word recognition: A masked priming ERP investigation. *Cognitive, Affective, & Behavioral Neuroscience*, 19, 966–984. https://doi.org/10.3758/s13415-019-00696-1

Hermena, E. W., Drieghe, D., Hellmuth, S., & Liversedge, S. P. (2015). Processing of Arabic diacritical marks: Phonological–syntactic disambiguation of homographic verbs and visual crowding effects. *Journal of Experimental Psychology: Human Perception and Performance*, 41, 494–507. https://doi.org/10.1037/xhp0000032

Hermena, E. W., & Reichle, E. D. (2020). Insights from the study of Arabic reading. *Language and Linguistics Compass*, 14, 1–26.

Hermena, E. W., Liversedge, S. P., & Drieghe, D. (2016). Parafoveal processing of arabic diacritical marks. *Journal of Experimental Psychology: Human Perception and Performance*, 42, 2021–2038. https://doi.org/10.1037/xhp0000294

Kinoshita, S., Amos, A., & Norris, D. (2023). Diacritic priming in novice readers of diacritics. *Journal of Experimental Psychology: Human Perception and Performance*, 49, 370.

Kinoshita, S., & Kaplan, L. (2008). Priming of abstract letter identities in the letter match task. *Quarterly Journal of Experimental Psychology*, 61, 1873–1885. https://doi.org/10.1080/17470210701781114

Kinoshita, S., Yu, L., Verdonschot, R. G., & Norris, D. (2021). Letter identity and visual similarity in the processing of diacritic letters. *Memory & Cognition*, 49, 815–825. https://doi.org/10.3758/s13421-020-01125-2

Lally, C., & Rastle, K. (2022). Orthographic and feature-level contributions to letter identification. *Quarterly Journal of Experimental Psychology,* 76. https://doi.org/10.1177/17470218221106155

Marcet, A., Fernández-López, M., Baciero, A., Sesé, A., & Perea, M. (2022). What are the letters e and é in a language with vowel reduction? The case of Catalan. *Applied Psycholinguistics*, 43, 193–210. https://doi.org/10.1017/S0142716421000497

Marcet, A., Fernández-López, M., Labusch, M., & Perea, M. (2021). The omission of accent marks does not hinder word recognition: Evidence from Spanish. *Frontiers in Psychology*, 12, 794923. https://doi.org/10.3389/fpsyg.2021.794923

Marcet, A., & Perea, M. (2017). Is nevtral NEUTRAL? visual similarity effects in the early phases of written-word recognition. *Psychonomic Bulletin & Review*, 24, 1180–1185. https://doi.org/10.3758/s13423-016-1180-9

Marcet, A., & Perea, M. (2018a). Can I order a burger at rnacdonalds.com? Visual similarity effects of multi-letter combinations at the early stages of word recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 44, 699–706. https://doi.org/10.1037/xlm0000477

Marcet, A., & Perea, M. (2018b). Visual letter similarity effects during sentence reading: Evidence from the boundary technique. *Acta Psychologica*, 190, 142–149. https://doi.org/10.1016/j.actpsy.2018.08.007

Norris, D., & Kinoshita, S. (2012). Reading through a noisy channel: Why there's nothing special about the perception of orthography. *Psychological Review*, 119, 517–545. https://doi.org/10.1037/a0028450

Okano, K., Grainger, J., & Holcomb, P. J. (2013). An ERP investigation of visual word recognition in syllabary scripts. *Cognitive, Affective, & Behavioral Neuroscience*, 13, 390–404. https://doi.org/10.3758/s13415-013-0149-7

Perea, M., Abu Mallouh, & Carreiras, M. (2014). Are root letters compulsory for lexical access in Semitic languages? The case of masked form-priming in Arabic. *Cognition*, 132, 491–500. https://doi.org/10.1016/j.cognition.2014.05.008

Perea, M., Abu Mallouh, R., Mohammed, A., Khalifa, B., & Carreiras, M. (2016). Do diacritical marks play a role at the early stages of word recognition in Arabic? *Frontiers in Psychology*, 7, 1255. https://doi.org/10.3389/fpsyg.2016.01255

Perea, M., Abu Mallouh, R., Mohammed, A., Khalifa, B., & Carreiras, M. (2018). Does visual letter similarity modulate masked form priming in young readers of Arabic? *Journal of Experimental Child Psychology*, 169, 110–117. https://doi.org/10.1016/j.jecp.2017.12.004

Perea, M., Fernández-López, M., & Marcet, A. (2020). What is the letter é? *Scientific Studies of Reading*, 24, 434–443. https://doi.org/10.1080/10888438.2019.1689570

Perea, M., Labusch, M., & Marcet, A. (2022). How are words with diacritical vowels represented in the mental lexicon? Evidence from Spanish and German. *Language, Cognition and Neuroscience*, 37, 457–468. https://doi.org/10.1080/23273798.2021.1985536

Pittrich, K., & Schroeder, S. (2023). Reading vertically and horizontally mirrored text: An eye movement investigation. *Quarterly Journal of Experimental Psychology*, 76, 271–283. https://doi.org/10.1177/17470218221085943

R Core Team (2021). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/

Riesenhuber, M., & Poggio, T. (1999). Hierarchical models of object recognition in cortex. *Nature Neuroscience*, 2(11), 1019–1025. https://doi.org/10.1038/14819

Treisman, A. (1982). Perceptual grouping and attention in visual search for features and for objects. *Journal of Experimental Psychology: Human Perception and Performance*, 8, 194–214. https://doi.org/10.1037/0096-1523.8.2.194

Vidal, C., Content, A., & Chetail, F. (2017). BACS: The Brussels Artificial Character Sets for studies in cognitive psychology and neuroscience. *Behavior Research Methods*, 49, 2093–2112. https://doi.org/10.3758/s13428-016-0844-8

Wiley, R. W., Wilson, C., & Rapp, B. (2016). The effects of alphabet and expertise on letter perception. *Journal of Experimental Psychology: Human Perception and Performance*, 42, 1186–1203. https://doi.org/10.1037/xhp0000213

Yakup, M., Abliz, W., Sereno, J., & Perea, M. (2015). Extending models of visual-word recognition to semicursive scripts: Evidence from masked priming in Uyghur. *Journal of Experimental Psychology: Human Perception and Performance*, 41, 1553.

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