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Are root letters compulsory for lexical access in Semitic languages? The case of masked form-priming in Arabic

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ABSTRACT

Do Semitic and Indo-European languages differ at a qualitative level? Recently, it has been claimed that lexical space in Semitic languages (e.g., Hebrew, Arabic) is mainly determined by morphological constraints, while lexical space in Indo-European languages is mainly determined by orthographic constraints (Frost, Kugler, Deutsch, & Forster, 2005). One of the key findings supporting the qualitative difference between Semitic and Indo-European languages is the absence of masked form priming in Hebrew/Arabic with productive words. Here we examined whether masked form priming occurs in Arabic words when one of the letters from the productive root is replaced in the prime stimulus by another letter. Results showed a significant masked form priming effect with the lexical decision task in three experiments (including yes/no, go/no-go, and sandwich priming), to a similar degree to that reported in previous research with Indo-European languages. These data support the view that the processing of word forms in Semitic vs. Indo-European languages differs more at a quantitative than at a qualitative level.

Introduction

In recent years, there has been increasing interest in the study of how the peculiarities of a language may shape the process of visual-word recognition (see Frost, 2012, for review). Critically for the present purposes, it has been claimed that lexical space in Semitic languages (e.g., Hebrew, Arabic) is primarily determined by morphological constraints (via the root morphemes) whereas lexical space in Indo-European languages is mainly affected by orthographic constraints (Frost, 2009; see also Velan & Frost, 2011). According to Frost, Kugler, Deutsch, and Forster (2005), "the perceptual distance between two words containing different roots [in Semitic languages] would be uncorrelated with their overall orthographic similarity." (p. 1296) This affirmation is based, originally, on one key effect that differs in Indo-European and Semitic languages: While there are a number of reports of facilitative masked form (orthographic) priming with one-letter substitution nonword primes in Indo-European languages (i.e., spuce-SPACE being responded to faster than wudow-SPACE; e.g., *English*: Forster, Davis, Schoknecht, & Carter, 1987; *French*: Ferrand & Grainger, 1992; *Spanish*: Perea & Rosa, 2000; *Dutch*: Brysbaert, 2001), this is absent in Semitic languages (see Frost et al., 2005; Velan & Frost, 2011, for failures to obtain a masked form priming effect in Hebrew and Arabic). Frost (2012) has argued that, unlike Indo-European languages, the "orthographic coding scheme of Hebrew print focuses mainly on the few letters that carry morphological information, whereas the other letters of the word do not serve for lexical access, at

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least not initially" (p. 9). Thus, in this view, sharing all the root letters would be a prerequisite for a facilitative masked priming effect in Semitic languages (Frost, 2009).

Before describing the relevant findings in detail, it is important to mention two key particularities of words in Semitic languages. First, Semitic words can be decomposed into two discontinuous morphemes: (i) a consonantal root (usually composed of three [or four] letters) which provides the core meaning of the word (e.g., the Semitic root k.t.b [writing or marking]; for transcriptions, we employ the Buckwalter transliteration scheme; see Boudelaa & Marslen-Wilson, 2010); and (ii) and a phonological word-pattern, which conveys morphosyntactic and phonological information. (In the following examples, the Cs represent the consonantal pattern.) Each set of root letters, together with a word pattern, can lead to a large number of words: كتاب kitAab = book (word pattern: CiCaaC), كاتب kAtib = writer (word pattern: CaCiC), مكتب maktab = office (word pattern: maCCaC), كتب kutub = books (word pattern: CuCuC), مكتوب maktuub = written (word pattern: maCCuuC) – note that short vowels in Arabic or Hebrew are not typically written down (e.g., the word kitAab [book] would be written as ktAB) so that words convey mostly consonantal information. In addition, in Hebrew and Arabic, there is a small proportion of: (i) words with a non-productive root (i.e., a consonantal root that only appears in that word, accompanied by a word pattern); and (ii) loan words that cannot be decomposed into a root and a word pattern (i.e., they have no internal structure). Second, the percentage of words sharing the same letters (in different order) in Semitic languages is dramatically higher than in Indo-European languages. This is so because the root letters may appear in different combinations forming unrelated morphological families (e.g., s.b.H ["to swim"], s.H.b ["to withdraw"], H.s.b ["to calculate"], or H.b.s ["to imprison"]). Indeed, the transposed-letter effects that can be easily obtained in Indo-European languages when transposing two letters in the lexeme (i.e., "cholocate" being processed as "chocolate"; e.g., see Perea & Lupker, 2004) is noticeably smaller when transposing two letters in the root in Semitic languages (Hebrew: Velan & Frost, 2007; Arabic: Perea, Abu Mallouh, & Carreiras, 2010).

But does the empirical evidence actually support "the qualitative difference in processing base forms" (Velan & Frost, 2011, p. 154) between Semitic and Indo-European languages? Frost et al. (2005; Experiment 2) failed to find significant masked form priming effects (via one-letter substitution primes) in Hebrew both when the word targets were composed of productive roots and when the word targets were composed of non-productive roots (the priming effects were 2 and 4 ms, respectively). This was interpreted as reflecting that, in Hebrew, "even words that are not morphologically complex are not stored according to a purely orthographic code" (p. 1306). However, Velan and Frost (2011, Experiment 4) conducted a parallel experiment and found a significant 11-ms masked form priming effect for word targets composed of non-productive roots. The parallel effect for the word targets composed of productive roots was a nonsignificant 6-ms priming effect. In that same experiment, Velan and Frost also reported a significant 16-ms masked form priming effect when the word targets were loan words (AGRTL אגרטל [a vase]) with no internal root + word pattern structure. The critical interaction between word type (productive, non-productive, loan) and prime condition (related, unrelated) in Velan and Frost's Experiment 4 was not close to significance in the analysis by items ($F2 < 1$). Thus, at the item level, all three types of words in the Velan and Frost experiment (i.e., including the words with productive roots) would be responsible for the main effect of masked form priming. Velan and Frost (2011) concluded, notwithstanding, that while Semitic words are clustered together in the lexical space as a function of their root letters (i.e., thus not showing masked form priming); words whose roots are not productive and words with no internal structure would be processed in a similar way to Indo-European languages (i.e., thus showing masked form priming). However, as Velan and Frost acknowledged, "this duality is not parsimonious." (p. 154).

There are many theorists – from different standpoints – who assume that the differences in word processing between Semitic and Indo-European languages are quantitative rather than qualitative. In their dual-route approach, Grainger and Ziegler (2011) indicated that the findings obtained in Hebrew could be due to a different balance in the priority given to fine-grained versus coarse-grained orthographic information relative to Indo-European languages. While fine-grained orthographic information "optimizes processing via the chunking of frequently co-occurring contiguous letter combinations", coarse-grained orthographic information "optimizes the mapping of orthography to semantics by selecting letter combinations that are the most informative with respect to word identity (diagnosticity), irrespective of letter contiguity" (Grainger & Ziegler, 2011, p. 3). In particular, Grainger and Ziegler (2011) argued that the lack of transposed-letter priming in productive Semitic words occurs because priority is given to fine-grained information when processing productive Semitic words (i.e., a quantitative rather than a qualitative difference among families of languages). Likewise, Davis (2012) argued that "the same coding and processing mechanisms as the spatial coding model" (p. 21) could be successfully applied to Semitic languages – for instance, Davis argued that the inhibitory transposed-letter priming with word–word pairs reported by Velan and Frost (2009) and Perea et al. (2010) could be explained in terms of lexical inhibition at the lexical level. Similarly, Whitney (2012) claimed that an open-bigram coding scheme could be well suited to Semitic languages and that any differences between Semitic and Indo-European languages in orthographic processing would reflect quantitative rather than qualitative differences.

One aspect in which the word-forms from Semitic and Indo-European languages may differ is in the internal structure – in particular in the regularities of root + word pattern sequences of Semitic words. It may be reasonably argued that readers of Semitic languages pick up the statistical regularities of these languages and this may alter how the word-forms are processed in comparison to word-forms from Indo-European languages. To examine this issue, Lerner, Amstrong, and Frost (2013) employed a multi-layer neural network that mapped orthographic inputs from five-letter words to semantic outputs via back-propagation. In their initial study, the network learned 1000 artificial words in two different scenarios: (i) an English-like lexicon, in which no anagrams could be formed from the words; and (ii) a Hebrew-like (Semitic) lexicon, in which all words had at least one anagram. To obtain a measure of facilitation comparable to the usual priming experiments, Lerner and cols. employed the correlations between the outputs to the learned words and new stimuli. Results revealed that the correlation between the target words and the new stimuli was substantially larger for the transposed-letter pairs in the English-like network than in the Hebrew-like network (.99 vs. .59, respectively), consistent with previous evidence on the vanishing transposed-letter effect in Hebrew (e.g., Velan & Frost, 2007). But the remarkable finding, for the present purposes, is that the amount of correlation between the learned words and the new words was exactly the <u>same</u> for the one-letter different pairs in the English-like network and in the Hebrew-like network (.16). In a second simulation study, Lerner and cols. (2013) selected 3000 real words from English in one scenario and from Hebrew in the other. Again, the correlation between the real words and the new stimuli was dramatically higher for the transposed-letter pairs in English than in Hebrew (.87 vs. .53, respectively), while for the one-letter different pairs, the correlation was only slightly higher in the English than in the Hebrew network (.13 vs. 09). Therefore, while letter transposition effects differ greatly across the two scenarios, this difference does not apply at the level of letter identity with one-letter substitution pairs. Indeed, the data from Lerner et al. (2013) does suggest, if anything, that the rigidity of the "root + word pattern" structures in Hebrew should not greatly affect the amount of masked form priming with one-letter substitution primes.

Given the theoretical importance of finding out whether or not lexical space in Semitic languages is organized in a qualitatively different way from Indo-European languages (cf. Frost, 2012 vs. Davis, 2012; Grainger & Ziegler, 2011; Whitney, 2012), here we examined whether it is possible to obtain masked form priming in Arabic using words with productive roots –note that this is a critical test regarding the existence of a qualitative difference between Semitic and Indo-European languages. As in the experiments of Frost et al. (2005) and Velan and Frost (2011), we employed a masked priming lexical decision task. A target word was preceded either by: i) a related prime nonword created by replacing one letter from the consonantal root; or ii) an unrelated prime nonword (i.e., analogous to the manipulation employed by Velan & Frost, 2011; Experiment 4, or Frost et al., 2005, Experiment 2). Given that the expected effects are presumably small, and to achieve enough experimental power to detect any differences, we selected a large set of 180 productive Arabic words (i.e., 90 words per relatedness level). (This number is substantially higher than the number of items per condition in Velan and Frost's (2011), Experiment 4: eight words per relatedness level.)

Three masked priming lexical decision experiments were conducted with adult skilled readers of Arabic. In Experiment 1, we employed the same type of nonword targets as Velan and Frost (2011) (i.e., the nonwords were created by changing a letter from the consonantal root in an existing word). Two blocks were presented, in one block we employed the yes/no version of the lexical decision task (i.e., participants had to respond to words and to nonwords), while in the other block we employed a go/no-go procedure (i.e., participants had to respond to the words and refrain from responding to the nonwords). The reason for including this extra manipulation is that the go/no-go procedure – while not altering the core processes (see Gomez, Ratcliff, & Perea, 2007, for modeling evidence) – has been shown to more sensitive to a small-sized manipulation than the yes/no procedure (e.g., see Bacon-Macé, Kirchner, Fabre-Thorpe, & Thorpe, 2007; Grice & Reed, 1992; Perea, Rosa, & Gómez, 2002; Siakaluk, Buchanan, & Westbury, 2003), presumably because of the task-specific decisional/motor demands from yes/no procedure. Experiment 2 was a replication of Experiment 1 except that the word/nonword discrimination was made easier by employing nonwords composed of consonants with no internal structure (e.g., <u>l&vnD,</u> لشتنص). Finally, Experiment 3 employed a yes/no lexical decision task with the nonwords from Experiment 1, in combination with a masked priming sandwich technique (Lupker & Davis, 2009). The rationale of this final experiment is that previous research has shown that this technique magnifies the magnitude of masked priming effects that may be difficult to detect in the standard masked priming paradigm (Lupker & Davis, 2009; see also Ktori, Grainger, Dufau, & Holcomb, 2012; Ziegler, Bertrand, Lété, & Grainger, 2013).

In sum, if the identification of the root letters is a prerequisite for masked form priming in Semitic words (as claimed by Frost, 2009; Velan & Frost, 2011), then one would expect no masked form priming effects at all for the word targets in any of the experiments. However, if orthographic processing is at play (as occurs in Indo-European languages), one would expect significant masked form priming effects in all the experiments. Finally, to have more stringent measures of the processes under scrutiny, we conducted not only the traditional analyses on the RTs (and percent error) – as in the Velan and Frost (2011; Frost et al. 2005) experiments, but we also examined the RT distributions of the related vs. unrelated condition. Recent experiments have revealed that masked repetition priming effects for word stimuli reveal a shift of the RT distributions (see Gomez, Perea, & Ratcliff, 2013). This is consistent with the idea of facilitation in terms of "savings" or encoding time rather than in changes in the "quality of information" (see Gomez et al., 2013, for discussion). If this benefit applies to form-priming as well, the magnitude of the masked form priming effect should be similar across quantiles.

2. Experiment 1 (masked priming: standard nonwords)

As in previous experiments in Arabic and Hebrew, primes and targets were presented in different font sizes to avoid physical continuity between primes and targets – Arabic does not have a lowercase/uppercase distinction (see Frost et al., 2005, for a similar procedure). It is important to note here that any priming effect obtained cannot be due to some residual "low-level peripheral" priming. In a recent series of experiments, Perea, Abu Mallouh, and Carreiras (2013) found that the magnitude of masked morphological priming in Arabic in adult skilled readers occurred to the same degree regardless of the visual similarity between the prime and the target (equivalent response times for visually similar pairs like كتزب - كتاب [ktzb-ktAb] and visually dissimilar pair like كتخب - كتاب [ktxb-ktAb]; the root was k.t.b).

2.1. Method

2.1.1. Participants

Twenty-four native speakers of Arabic, all of them students at the University of Valencia or at the Polytechnic University of Valencia, took part voluntarily in the experiment. All were born and studied elementary/secondary school in their home countries (in Arabic). All of them reported using Modern Standard Arabic on a daily basis and had normal (or corrected-to-normal) vision.

2.1.2. Materials

We selected a set of 180 Arabic words of five letters, all of them with productive roots. The mean frequency of these word forms was 25 appearances per million (range: 0.03–637) in the Aralex database of Modern Standard Arabic (Boudelaa & Marslen-Wilson, 2010). The mean number of one-letter substitution neighbors was 3.27 (range: 0–20). These words were preceded by prime stimuli that were: (1) the same as the target except for the substitution of a root letter (kxAbp-ktAbp: كخابة - كتابة; the root is كتب [k.t.b]), or 2) an unrelated stimulus (dAvly-ktAbp; داثلي - كتابة). There were 21 words in which the substitution occurred in the first position, 55 in the second position, 84 in the third position, and 20 in the fourth position. Substitution-letter primes were rotated throughout the related and unrelated conditions so that each target word was primed by each of the two types of primes across the experiment. The list of the prime–target stimuli (including the corresponding transliterations and the approximate English translations) is available at: http://www.uv.es/mperea/FormPrimingArabicExpts.pdf. An additional set of 180 nonwords of five letters was created for the purposes of the lexical decision task. These nonwords had been created by replacing a letter from the root from an Arabic word (e.g., the pseudoword mrZEp مرظعة; the base-word is mrbEp, مربعة [square], the root is rbE ربع, i.e., it was the same procedure as in the Velan & Frost, 2011, study). The manipulation of the nonword trials was the same as that for the word trials. Two lists of materials were constructed in each subexperiment (i.e., four lists in total), so that each target appeared once in each list, but each time in a different priming condition (related vs. unrelated). Different groups of participants made up each list.

2.1.3. Procedure

Participants were tested individually or in groups of two in a quiet room. Presentation of the stimuli and recording of response times were controlled by DMDX software (Forster & Forster, 2003). On each trial, a forward mask consisting of a row of hash marks (######) was presented for 500 ms in the center of the screen. Next, at the same location, the prime was presented in 24-pt Arabic font for 50 ms (3 cycles on a 16-Hz CRT screen). The prime was then replaced by the presentation of the target stimulus in 36-pt. Arabic font. The target remained on the screen until the participants responded – or until 2.5 s had elapsed. Response times were measured from target onset to the participant response. Participants were not informed of the presence of briefly presented stimuli. In the go/no-go blocks, participants were instructed to press the "yes" button if the letter string was a real word in Arabic, and refrain from responding if the letter string did not form an Arabic word. Participants were instructed to make this decision as quickly and as accurately as possible, and none of them reported (after the experiment) conscious knowledge of the existence of any prime. In the yes/no block, participants were instructed to press the "yes" button if the letter string was a real word in Arabic and the "no" button if the letter string did not form a word in Arabic. In each block, participant received a different order of trials and a total of 20 practice trials (with the same manipulation as in the experimental trials) prior to the 180 experimental trials (90 word trials: 45 related, 45 unrelated; 90 nonword trials: 45 related, 45 unrelated). Half of the participants started with the yes/no block and then the go/no-block, and the other half started with the go/no-block and then the yes/no block. Although participants reported not having seen the prime stimuli, after the two blocks and to test the availability on information from the primes, all participants were asked to perform a yes/no lexical decision task on the prime stimuli – using the same setup as in the experiment – on a set of 80 trials (20 word–word pairs, 20 word–nonword pairs, 20 nonword–word pairs, and 20 nonword–nonword pairs; all the stimuli were five letters in length. These materials were extracted from the pairs used by Perea et al. (2013). The whole session lasted approximately 30 min.

2.2. Results and Discussion

Incorrect responses (3.3 and 1.9% for the word targets in the yes/no and go/no-go subexperiments, respectively) and lexical decision times less than 250 ms or greater than 1500 ms (0.9 and 1.8% of the data for the word targets in the yes/no and go/no-go subexperiments, respectively) were excluded from the latency analysis. The order of the tasks had no effect and was not further analyzed (see Gomez et al., 2013). The lexical decision on the prime stimuli and accuracy for the word and nonword primes was approximately at chance level (45.9 and 50.6%, respectively; see Forster et al., 1987, for a similar finding) – we excluded the data from five of the participants who could not perform this task (i.e., the deadline occurred before the responses). The RT distributions were analyzed using the .1, .3., .5, .7, and .9 quantiles (see Gomez et al., 2007, 2013, for a similar analysis) and the corresponding ANOVAs included Task procedure [yes–no vs. go/no-go] and prime–target relatedness [related vs. unrelated] as factors – List was also included as a dummy factor in the ANOVAs (see Pollatsek & Well, 1995).

In addition, we also analyzed the latency and error data through linear mixed-model (LMM) effects ("lme4" library, version 1.0-5 [Bates, Maechler, & Bolker, 2013] in R [R Core Team, 2013]) using Task procedure [yes–no vs. go/no-go] and prime–target relatedness [related vs. unrelated] as fixed effects with the maximal random structure (i.e., random slopes corresponded to the combination of the two within-subject factors; see Barr, Levy, Scheepers, & Tilly, 2013). On the basis of Q–Q plots, we performed an inverse transformation to the RTs (−1000/RT) so that the distributions were closer to the Gaussian distribution (see Baayen & Milin, 2010). Given that no exact p-values can be obtained from the t values in LMMs, and given that we had thousands of data (more than 4000 RTs; i.e., "the t distribution has converged, for all practical purposes, to the standard normal distribution" [Baayen, Davidson, & Bates, 2008, p. 398]), we assumed t values over 2.00 to be significant –for the critical effects, model comparisons (with vs. without the effect of interest) via likelihood tests confirmed those effects. For the error data, the Laplace approximation was employed to obtain p-values. (We should note here that the pattern of data obtained with the LMM analyses was parallel to that obtained with the standard ANOVAs by participants and by items.)

Visual inspection of Fig. 1 reveals an advantage of the related over the unrelated condition for word targets, which was confirmed in the ANOVA, $F(1,20) = 28.09$, MSE = 1380, $p < .001$. This form priming effect was qualified by an interaction between relatedness and quantile, $F(4,80) = 6.35$, MSE = 2355, $p = .02$. In particular, the go/no-go variant of the lexical decision task revealed a masked form priming effect of approximately similar magnitude across quantiles (32, 31, 39, 33, and 10 ms at the .1, .3, .5, .7, and .9 quantiles; main effect of relatedness, $F(1,20) = 24.10$, MSE = 2116, $p < .001$; interaction relatedness × quantile: $F(4,80) = 1.47$, MSE = 984, $p = .21$). In contrast, the analyses on the yes/no variant of the lexical decision task revealed that the form priming effect varied across quantiles (interaction: $F(4,80) = 4.29$, MSE = 783, $p = .003$): this revealed a sizeable effect of relatedness at the .1, .3 and .5 quantiles (14, 20, and 16 ms, respectively), while the effect vanished at the higher .7 and .9 quantiles (4 and −21 ms, respectively) – note that the .5 quantile (i.e., the median RT) produced a sizeable 16-ms priming effect ($F(1,20) = 11.59$, MSE = 273, $p = .003$). For the nonword targets, the magnitude of the effect of form priming was also significant, $F(1,20) = 7.62$, MSE = 5520, $p = .012$; and its size increased at the higher quantiles (13, 20, 19, 28, and 52 ms, at the .1, .3, .5, .7, and .9 quantiles), as deduced from the interaction between relatedness and quantile: $F(4,80) = 2.84$, MSE = 1003, $p = .03$).

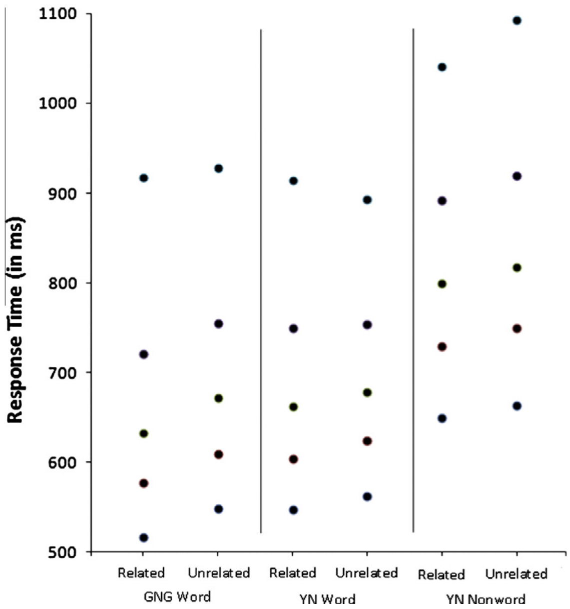

Fig. 1. Group response time distributions in the different conditions of Experiment 1. The black dots represent the .1, .3, .5, .7, and .9 quantiles.

The statistical analyses using LMMs revealed that target words were responded to faster when they were preceded by a form-related prime than when they were preceded by an unrelated prime, $t = 3.56$, $b = 0.062$, SE = 0.017. In addition, responses were faster in the go/no-go than in the yes/no blocks, $t = 1.97$, $b = 0.062$, SE = 0.032. Finally, the relatedness effect was not significantly modulated by task, but there was a nonsignificant trend, $t = 1.84$, $b = 0.026$, SE = 0.014. As revealed by the RT distributions, the effect of relatedness was more robust in the go/no-go procedure, $t = 3.44$, $b = 0.061$, SE = 0.018, than in the yes/no procedure, $t = 1.84$, $b = 0.026$, SE = 0.014,

The analyses on the error rates only revealed that participants committed more errors with the yes/no procedure than with the go/no-go procedure, $z = -3.74$, $b = -1.39$, SE = 0.37, $p < .001$.

2.2.1. Nonword data

The error data did not reveal a significant effect. Finally, the latency data in the yes/no task revealed a non-significant advantage of the related over the unrelated condition, $t = 1.84$, $b = .026$, SE = 0.014.

In the present experiment, there was no evidence that the effects obtained were due to some "leaking" availability of the primes. Furthermore, as expected, participants made more errors in the yes/no than in the go/no-go variant of the lexical decision task (Gomez et al., 2007).

More importantly, we found a sizeable masked form priming effect in Arabic for word targets. This was particularly clear in the go/no-go version of the lexical decision task. The form priming effect was approximately similar across quantiles (i.e., there was a shift in the RT distributions, similar to the Gomez et al., 2013, masked repetition priming experiment) and the LMM results confirmed this finding. However, the outcome with the yes/no variant of the lexical decision task is not completely unambiguous. The TR distributional analyses revealed a relatedness effect in the lower quantiles, up to the median (see Fig. 1; note that the median RT revealed a significant 16-ms effect), but then the relatedness effect disappeared (and turned inhibitory) at the higher .9 quantile. Given that an inverse transformation was computed, long response times weighted less than in an untransformed set and the LMM analysis revealed a nonsignificant advantage ($t = 1.84$) of relatedness in the yes/no lexical decision task. However, when computing the mean RTs on the raw data, the advantage was reduced to a 5-ms difference. This suggests that there are two processes at play (i.e., facilitation at an early encoding stage, and some inhibition at a later stage) that may have obscured the relatedness effect in the yes/no task. A similar pattern (i.e., facilitation at the lower quantiles and inhibition at the higher quantiles) was reported by Gomez et al. (2013) with masked repetition priming on nonword targets. We believe that the lack of a facilitative effect of relatedness in the higher quantiles could have been due to the extra decisional processes involved in two-choice paradigms (Gomez et al., 2007). To test this possibility, and to further examine the presence of masked form priming in Arabic, we employed the same word targets in a scenario in which the decisional processes were easier: using consonants with no internal structure as (nonword) foils. This was the goal of Experiment 2.

Finally, we found there was some form-priming for nonword targets, which was apparent in the RT distributional analyses – the evidence from the LMM analyses was less clear (see Frost, Ahissar, Gottesman, & Tayeb, 2003; Tzur & Frost, 2007, for several instances of masked priming effects for nonwords in Hebrew).

3. Experiment 2 (masked priming: easy nonwords)

3.1. Method

3.1.1. Participants

Twenty-four native speakers of Arabic, all of them undergraduate students at the University of Palestine in Gaza took part voluntarily in the experiment. They reported using Modern Standard Arabic on a daily basis and had normal or corrected-to-normal vision.

3.1.2. Materials

All the word trials were the same as in Experiment 1. The only difference is that the nonword targets were random sequences of consonants (e.g., l&vnD, لشثنض).

3.1.3. Procedure

It was the same as in Experiment 1.

3.2. Results and discussion

Incorrect responses (3.8 and 0.6% for the words in the yes/no and go/no-go blocks, respectively) and RTs less than 250 ms or greater than 1500 ms (0.5 and 0.3% of the data for the word targets in the yes/no and go/no-go blocks, respectively) were excluded from the RT analysis. The statistical analyses were parallel to those in Experiment 1.

Visual inspection of Fig. 2 reveals an advantage of the related over the unrelated condition for word targets, which was confirmed in the ANOVA, $F(1,20) = 8.41$, $MSE = 2533$, $p = .009$, while none of the interactions approached significance (all $ps > .25$) – note that the magnitude of masked form priming was approximately similar across quantiles in the go/no-go procedure (13, 11, 16, 7, and 14 ms, at the .1, .3, .5, .7, and .9 quantiles, respectively) and in the yes/no-procedure (24, 21, 12, 13, and 3 ms, at the .1, .3, .5, .7, and .9 quantiles). For nonword trials, the relatedness effect (8, 11, 13, 4, and −1 ms, at the .1, .3, .5, .7, and .9 quantiles, respectively) approached significance, $F(1,20) = 3.43$, $MSE = 1798$, $p = .079$ (see Fig. 3).

3.2.1. Word data

The ANOVA on the mean RTs revealed that target words were responded to faster when they were preceded by a form-related prime than when they were preceded by an unrelated prime, $t = 2.55$, $b = 0.049$, $SE = 0.019$. Unlike Experiment 1, there were no signs of an interaction between the two factors, $t < 1$. Again, response times were somewhat faster in the go/no-go than in the yes/no version of the lexical decision task, but the difference was not significant, $t = 1.08$, $b = 0.049$, $SE = 0.046$.

The analysis on the error data only revealed that participants committed more errors in the yes/no procedure than in the go/no-go procedure, $z = 4.81$, $b = -2.17$, $SE = 0.45$, $p < .001$ and that participants committed fewer errors in

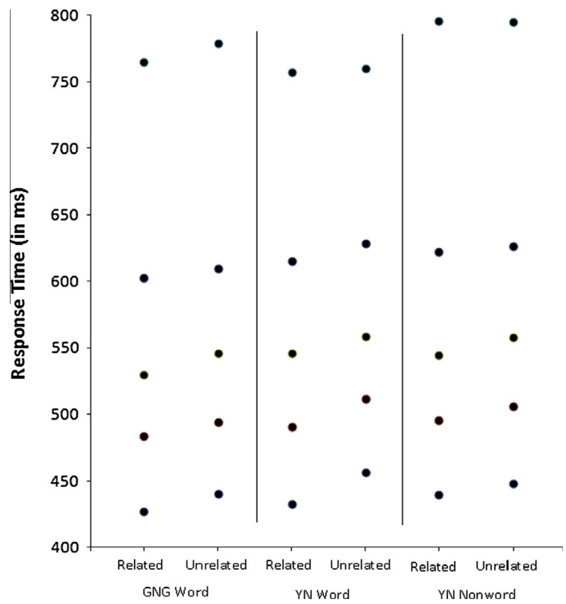

Fig. 2. Group response time distributions in the different conditions of Experiment 2. The black dots represent the .1, .3, .5, .7, and .9 quantiles.

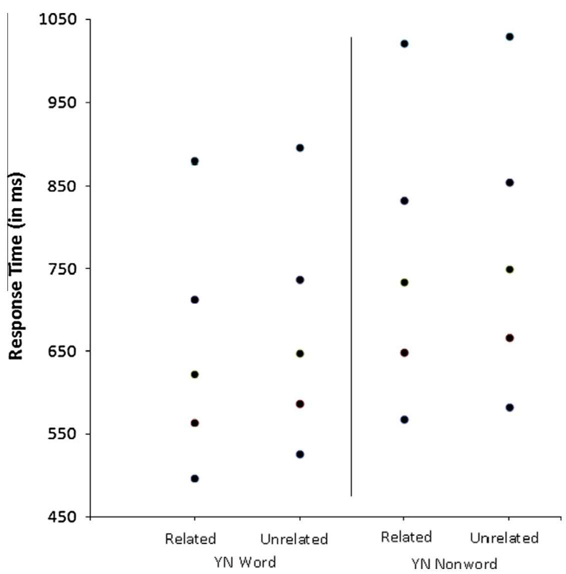

Fig. 3. Group response time distributions in the different conditions of Experiment 3. The black dots represent the .1, .3, .5, .7, and .9 quantiles.

the related than in the unrelated condition, $z = 2.50$, $b = .1.02$, $SE = 0.41$, $p = .012$.

3.2.2. Nonword data

The analysis on the error data only revealed that participants committed more errors in the yes/no procedure than in the go/no-go procedure, but the difference was not significant, $z = 1.90$, $b = 0.55$, $SE = 0.29$, $p = 0.57$ – the other effects did not approach significance (both $ps > .60$). Finally, the latency data in the yes/no task revealed a non-significant advantage of the related over the unrelated condition, $t = 1.82$, $b = .034$, $SE = 0.019$.

The present experiment successfully replicated the masked form priming effect obtained in Experiment 1 – this time with consonant strings (with no internal structure) as nonwords. The basic difference across experiments is that when the task was easier, the magnitude of masked form priming was similar in size to the yes/no and go/no-go procedure. Importantly, the RT distributions of the related and unrelated form-priming conditions revealed a shift, thus suggesting that the relatedness effect has its origin in a lower encoding time (i.e., a "savings" effect) in the related priming condition (see Gomez et al., 2013).

The only remaining puzzling finding – which nonetheless is consistent with previous research by Frost and colleagues – is that the masked form priming effect did not occur in the traditional "mean RT" of the yes/no version of the lexical decision task with difficult nonword foils (i.e., a 5-ms effect) – note, however, that the effect was noticeable in the RT distribution and the median RT revealed a significant 16-m effect (see Fig. 1).

In several recent experiments in English, Lupker and Davis (2009) have provided convincing evidence that a brief presentation of the target just before the masked prime boosts the size of (otherwise) small masked priming effects. Using French stimuli, Ktori et al. (2012) obtained a similar boost of the size of the masked priming effects when measuring ERPs, and Ziegler et al. (2013) successfully employed this technique in experiments with developing readers. Therefore, if orthographic priming is a reliable effect in Arabic, and there is a boost in the size of masked form priming with the sandwich technique, then a masked form priming effect in Arabic should be manifest with this procedure.

4. Experiment 3 (masked sandwich priming; yes/no variant of the lexical decision task with standard nonwords)

4.1. Method

4.1.1. Participants

Twenty native speakers of Arabic, from the same population as in Experiment 1, participated voluntarily in the experiment. None of them had taken part in Experiment 1.

4.1.2. Materials

They were the same as in Experiment 1 – the only difference is that only two lists were employed since task procedure was always the same (i.e., yes/no procedure). There were 360 trials (180 word trials: 90 related, 90 unrelated; 180 nonword trials: 90 related, 90 unrelated).

4.1.3. Procedure

The procedure was the same as in the yes/no block of Experiments 1 and 2. The only difference was the inclusion of the target stimulus immediately after the forward mask. Specifically, this is the setup of a typical trial with the sandwich technique: First, a forward mask consisting of a row of hash marks (######) was presented for 500 ms. Second, the target was presented in 36-pt. Arabic font for 33 ms. Third, the prime was presented in 24-pt. Arabic font for 50 ms. Finally, the prime was followed immediately by the presentation of the target stimulus in 36-pt. Arabic font. As in the previous experiments, the target remained on the screen until the participants responded – or until 2.5 s had elapsed. The whole session lasted approximately 15 min.

4.2. Results and discussion

Incorrect responses (5.8% for the word targets) and lexical decision times less than 250 ms or greater than 1500 ms (1.2% of the data for the word targets) were excluded from the latency analysis. The statistical analyses were parallel to those in Experiments 1 and 2, except that "task procedure" was not a factor in the present experiment.

Visual inspection of the RT distributions of word trials revealed an advantage of the related over the unrelated condition, which was confirmed by the ANOVA, $F(1,18) = 11.50$, $MSE = 2230$, $p = .003$. The magnitude of the relatedness effect was approximately the same across quantiles (29, 23, 25, 25, and 15 ms at the .1, .3, .5, .7, and .9 quantiles, respectively), as deduced from the lack of interaction between relatedness and quantile, $F < 1$. For nonword trials, the magnitude of the relatedness effect was also similar across quantiles (14, 17, 16, 22, and 8 ms at the .1, .3, .5, .7, and .9 quantiles, respectively; main effect of relatedness: $F(1,18) = 7.80$, $MSE = 1478$, $p = .012$; interaction relatedness $\times$ quantile: $F < 1$) (see Tables 1 and 2).

4.2.1. Word data

The ANOVA on the latency data revealed that target words were responded to faster when they were preceded by a form-related prime than when they were preceded by an unrelated prime, $t = 4.90$, $b = 0.069$, $SE = 0.014$. As can be seen in Table 3, the analyses on the error rates did not reveal any signs of a relatedness effect.

Table 1
Mean lexical decision times (in ms) and percentage of errors (in parentheses) for word and nonword targets in Experiment 1.

	Related	Unrelated	Unrelated–related
Yes/no LDT			
Words	704 (5.3)	709 (4.7)	5 (−0.6)
Nonwords	826 (14.9)	854 (14.7)	28 (−0.2)
Go/no-go LDT			
Words	684 (3.1)	710 (2.6)	26 (−0.4)
Nonwords	– (11.5)	– (11.7)	– (0.2)

Table 2
Mean lexical decision times (in ms) and percentage of errors (in parentheses) for word and nonword targets in Experiment 2 (easy nonwords).

	Related	Unrelated	Unrelated–related
Yes/no LDT			
Words	576 (4.5)	593 (6.3)	17 (1.8)
Nonwords	589 (4.6)	597 (5.1)	8 (0.5)
Go/no-go LDT			
Words	568 (2.2)	581 (1.9)	13 (−0.3)
Nonwords	– (3.3)	– (3.1)	– (−0.2)

Table 3
Mean lexical decision times (in ms) and percentage of errors (in parentheses) for word and nonword targets in Experiment 3 (sandwich priming with the yes/no LDT).

	Related	Unrelated	Unrelated–related
Words	663 (5.9)	686 (5.7)	23 (−0.1)
Nonwords	766 (11.1)	783 (10.6)	17 (−0.5)

4.2.2. Nonword data

Target words were responded to faster when preceded by a form-related nonword prime than when preceded by an unrelated nonword prime, $\underline{t} = 3.43$, $\underline{b} = 0.035$, $\underline{SE} = 0.010$. There were no signs of a relatedness effect in the error data – although the LMM analyses on the error rates did not converge, the "classical" $\underline{F}$ ratio was less than 1.

The present sandwich experiment revealed a substantial masked form-priming effect for target words. This pattern is consistent with the idea that the sandwich priming technique magnifies the size of masked priming effects (Lupker & Davis, 2009; see also Ktori et al., 2012; Ziegler et al., 2013). The RT distribution analyses revealed that the masked form priming effect occurred to a similar degree across quantiles – i.e., it suggests that there is a benefit in encoding time.

5. General discussion

In a number of papers, Frost and cols. (2005; Frost, 2009; Velan & Frost, 2011) claimed that there is qualitative difference between the processing of word forms in Semitic and Indo-European languages. One of the tenets of this affirmation is that early word processing in Semitic languages (as measured by masked priming) is driven solely on the basis of the root letters. If this is so, a masked nonword prime that does not convey all the consonantal root information should not produce noticeable (form) priming on the processing of a productive Semitic word. The present experiments were designed to examine whether masked form priming occurs when the prime did not contain all the root letters of the productive word in a Semitic language, Arabic. Results in all three experiments revealed a masked form priming effect (i.e., kxAbp-ktAbp [كتابة - كخابة] was responded to faster than dAvly-ktAbp [كتابة - داثلي]; the root is k.t.b [كتب]). In Experiment 1, using standard nonwords as foils, we found a sizeable masked form priming effect in the go/no-go variant of the lexical decision task – the evidence in the yes/no variant was not completely clear-cut (i.e., the RT distribution revealed a relatedness effect in the lower quantiles [including the median], but the effect vanished at higher quantiles, and the net result was a non-significant effect in the mean RTs). In Experiment 2, we employed consonant strings as foils, and found a sizeable masked form priming effect in the two varieties of the lexical decision task –this paralleled the RT distributional analyses. And, finally, in Experiment 3, using a masked sandwich technique, we found a sizeable masked form priming effect in a yes/no lexical decision task with standard pseudowords –again, this paralleled the RT distributional analyses.

Overall, this pattern of data reveals that orthographic elements play a role during the early stages of the processing of word forms in a Semitic language, Arabic – even in words with productive roots – presumably in terms of encoding time or savings as revealed by the RT distributions (see Gomez et al., 2013). It is important to note that the observed priming effects were not due to some residual "low-level peripheral" effect. Prior research in Arabic (Perea et al., 2013) has revealed that masked priming occurred to the same degree when the prime and target looked visually similar (e.g., كتاب - كتزب [ktzb-ktAb]; note that the ligation pattern is the same in prime and target) or not (كتاب - كتخب [ktxb-ktAb]). That is, masked priming effects in lexical decision in Arabic occur at an abstract level of representation. Furthermore, recent masked priming evidence has demonstrated that isolated letters in Arabic – which may change in shape depending on their position in a word – are also processed at an abstract level and follow a similar trajectory as (lowercase/uppercase) letters in the Roman alphabet: from visual features to abstract representations (Carreiras, Perea, & Abu Mallouh, 2012; Carreiras, Perea, Gil-López, Abu Mallouh, & Salillas, 2013). Finally, the presence of masked priming effects for nonwords in Semitic languages is not new (e.g., see Frost et al., 2003; Tzur & Frost, 2007, for a few instances) and, as occurs in Indo-European languages (see Perea & Rosa, 2000), masked priming effects for nonwords are often inconsistent and negligible (e.g., Frost et al., 2005). We should stress here that, in the present series of experiments, our focus is on the processes underlying lexical access (i.e. "yes" responses to words) rather than in the examination of how participants make "no" responses to the nonword foils. In particular, there is convincing evidence demonstrating that correct lexical decisions to word stimuli in masked priming (i.e., "yes" responses to words) are based on a lexical level (rather than a letter level) of processing (see Norris & Kinoshita, 2008).

The presence of masked form priming in Arabic is entirely consistent with the claims of Grainger and Ziegler (2011), Davis (2012), and Whitney (2012) that the differences in the processing of word forms between Semitic and Indo-European languages are quantitative rather than qualitative. Indeed, the inconsistencies between Velan and Frost's (2011) Experiment 4 and the present experiments is more apparent than real: We must keep in mind that they found no signs of an interaction between the masked form priming (related vs. unrelated) and type of word (productive, non-productive, loan) at the item level ($\underline{F}2 < 1$), which means that all three types of words – i.e., including the words with productive roots – were responsible for the effect of masked form priming. Of course, we acknowledge that the particularities of each language may shape a number of aspects of orthographic, phonological, and morphological processing (e.g., see Winskel, Perea, & Ratitamkul, 2013, for evidence in Thai, or Lee & Taft, 2009, for evidence in Korean). On the basis of the highly regular internal structure of Semitic words (see Frost, Siegelman, Narkiss, & Afek, 2013; Frost et al., 2005), morphological elements may play a greater role in Semitic languages than in Indo-European languages. After all, when looking up words in an Arabic dictionary, words are typically arranged by root words, instead of the alphabetical listing of word forms common to Indo-European languages. There is indeed empirical evidence that shows that the order of the root letters is key in the transposed-letter effect reported in Hebrew and Arabic (Velan & Frost, 2009, 2011; see also Perea et al., 2010), but not in Indo-European languages (e.g., Christianson, Johnson, & Rayner, 2005; Duñabeitia, Perea, & Carreiras, 2007). As the simulation data from Lerner et al. (2013) revealed, if readers pick up the statistical regularities of Semitic languages, a somewhat rigid letter coding scheme would naturally emerge. This idea also explains why, in Maltese – despite being a Semitic language, transposed-letter are effects comparable to those in English (see Perea, Gatt, Moret-Tatay, & Fabri, 2012). The reason is that there is a vast proportion of non-Semitic words in the Maltese lexicon (e.g., mostly from English, Italian, and Sicilian), so that the emerging network of statistical regularities may yield a pattern closer to that of Indo-European languages than Hebrew or Arabic. Nonetheless, the critical point here is that all these effects can be explained in terms of quantitative rather than qualitative differences (e.g., see Davis, 2012; Grainger & Ziegler, 2011; Whitney, 2012). Similarly, inter-individual differences in masked priming effects are explained in quantitative rather than qualitative terms (e.g., see Andrews & Hersch, 2010; Andrews & Lo, 2012, for examples of differences in masked form priming in English as a function of reading skill).

The present experiments were conducted in Arabic, while the vast majority of the experiments conducted by Frost and cols. (2005; Velan & Frost, 2011) were carried out in Hebrew – the exception being Experiment 5 in Frost et al. (2005). It may be important to note that, at a morphological level, there are a number of differences between Arabic and Hebrew (see Daya, Roth, & Wintner, 2008): (i) the number of roots in Arabic is nearly twice than that in Hebrew; (ii) the number of word patterns is substantially higher in Arabic than in Hebrew; and (iii), the number of possible intervening letters between root letters in Arabic is also higher than in Hebrew. All these different features may modulate the strength of the orthographic and morphological effects in Hebrew and Arabic. Future research should examine whether these differences may affect the way word forms are processed in Arabic vs. Hebrew, with special attention to the analyses of the RT distributions – note however that the central claims made by Frost and cols. (2005; Frost, 2009, 2012) apply equally to Hebrew and Arabic.

To sum up, the present masked form priming experiments have demonstrated that, early in word processing, purely orthographic effects can be obtained in a Semitic language, Arabic. This outcome, which is similar to prior reports in Indo-European languages, is more consistent with a quantitative rather than with a qualitative difference between the processing of word forms in Semitic vs. Indo-European languages. Future research should shed more light on other potential signatures of the processing of word forms in Semitic vs. Indo-European languages (e.g., comparing morphological vs. orthographic "markers" in learners of Semitic languages, see Frost et al., 2013).

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