Published in final edited form as:
Dev Sci. 2013 July ; 16(4): . doi:10.1111/desc.12052.

Early access to abstract representations in developing readers: Evidence from masked priming

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Abstract

A commonly shared assumption in the field of visual-word recognition is that retinotopic representations are rapidly converted into abstract representations. Here we examine the role of visual form vs. abstract representations during the early stages of word processing –as measured by masked priming– in young children (3rd and 6th graders) and adult readers. To maximize the chances of detecting an effect of visual form, we employed a language with a very intricate orthography, Arabic. If visual form plays a role in the early moments of processing, greater benefit would be expected from related primes that have the same visual form (in terms of the ligation pattern between a word's letters) as the target word (e.g., كتاب-كتزب [ktzb-ktAb] –note that the three initial letters are connected in prime and target) than for those that do not (كتاب-كتخب [ktxb-ktAb]). Results showed that the magnitude of priming effect relative to an unrelated condition (e.g., كتاب-طيار) was remarkably similar for both types of primes. Thus, despite the visual complexity of Arabic orthography, there is fast access to the abstract letter representations not only in adult readers by also in developing readers.

Keywords

word_recognition; reading_development; masked_priming

Both printed and *handwritten* letters in a written word can have enormous variations at the visual level (e.g., DENIED, *denied*, and denied activate the same lexical entry) and yet readers have little trouble identifying these words. At the neural level, a bank of "abstract letter detectors" has been hypothesized to be located in the human visual cortical area V8. (see Dehaene, Cohen, Sigman, & Vinckier, 2008, for a hierarchical model of visual-word recognition). As Grainger, Rey, and Dufau (2008) indicated, "visual features are mapped onto abstract letter identities via a series of increasingly invariant representations" (p. 384). ERP evidence suggests that access to these abstract letter identities can be achieved during the initial 200 ms of processing (see Grainger et al., 2008, for a neural model of letter perception). Clearly, mastering letter/word recognition at an abstract level of representation beyond the peculiarities of font, size, shape, etc., of the initial retinotopic representation is a critical skill for young readers in alphabetic orthographies. The discrimination of conceptual-featural differences among alphanumeric characters leads young readers to quickly develop specialized perceptual skills and thus to correctly identify letters, even after a very short experience with print or handwriting (e.g., Guttentag & Haith, 1980; Kaye, Brown, Post, &

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Pludem, 1981; Stanovich, 1980). Previous evidence suggests that the orthographic encoding mechanisms responsible for letter identification become settled at the initial stages of reading/writing acquisition and that they are hardly modulated with increased exposure to print (e.g., Kaye et al., 1981; see also Paap, Newsome, & Noel, 1984; Perea & Rosa, 2002).

How can the cognitive system respond similarly to visually dissimilar variants of a given letter (i.e., allographs like A, a, a, a)? Using the proposal that "synaptic plasticity mechanisms are sensitive to correlations", Polk et al. (2009, p. 88; see also Polk & Farah, 1997) showed that a neural network can learn contextual correlations that activate abstract letter representations regardless of the visual features of a given letter (i.e., a, a, and A activate the node corresponding to the letter "a"). Similarly, Hinton (2007) demonstrated that a multilayer neural network could readily learn to recognize handwritten digits (e.g., , , and , as instances of the digit "2"). In visual-word recognition, it has been suggested that this process can be modulated by phonology on the basis that allographs like "a", "A", and "a" produce the same sound (Bowers & Michita, 1998).

Evidence from adult readers supports the view that visual-word recognition involves an abstract code of a word's constituent letters. In an influential paper, Bowers, Vigliocco, and Haan (1998) employed a masked priming procedure to examine the role of visual vs. abstract representations during the early stages of word processing (Forster & Davis, 1984; see Grainger, 2008, for review). In this technique, a forwardly masked prime item (e.g., edge) is presented very briefly (around 30-50 ms) and is followed by a target item (e.g., EDGE). Bowers and colleagues selected two sets of stimuli. In one set, lower- and uppercase forms were visually similar (e.g., prime: kiss, target: KISS), whereas in the other set, lower- and uppercase forms were visually dissimilar (e.g., edge-EDGE). If visual similarity plays a role in the early stages of visual-word recognition, a briefly-presented prime like kiss –which is visually similar in lowercase and uppercase– should produce more repetition priming on its corresponding uppercase target word than a prime like edge. Bowers et al. (2008) found that the size of masked repetition priming (relative to an unrelated control prime) was remarkably similar for the two sets of words in a lexical decision task (a word/nonword discrimination task) and in a verb/noun categorization task. Bowers and Turner (2005) replicated these findings when the primes and targets were lateralized to either left or right visual fields in a masked priming lexical decision experiment (see also Kinoshita & Norris, 2009, for a replication with the masked priming same-different task). Thus, findings with the Roman script reveal that, at least for adult skilled readers, there is early access to the abstract representation of the word's constituent letters (see also Gil-López, Perea, Moret-Tatay, & Carreiras, 2011, for evidence of masked repetition priming with primes; see also Hannagan, Ktori, Chanceaux, & Grainger, 2012, for evidence of masked repetition priming with CAPTCHAs [e.g.,] as primes).

The main goal of this study is to examine whether there are developmental differences in access to the abstract representations of a word's constituent letters at the early stages of processing, as measured by masked priming. The rationale is that the immature lexical system of developing readers may be more sensitive to the effects of visual form than the more mature lexical system of adult skilled readers ("lexical tuning" hypothesis: Castles, Davis, Cavalot, & Forster, 2007). In the present paper, we examined the role of visual form in the early moments of visual-word recognition with Grade 3 and Grade 6 children –for comparison purposes we also first conducted the experiment with adult readers (see Acha & Perea, 2008; Castles et al., 2007, for a similar approach). We should note here that, under the implicit assumption that abstract letter codes are rapidly activated during visual word processing, the visual similarity between the letters of the prime and the target (e.g., i-I or a-

A) has not been controlled in previous masked priming experiments with developing readers.

To maximize the chances of detecting an effect of visual form, we employed a language with very intricate orthography: Arabic. (footnote 1) Leaving aside that, unlike Indo-European languages, Arabic is written/read from right to left, Arabic orthography has a number of features that make the role of visual form highly salient. Firstly, Arabic is written in semi-cursive form: twenty-two of the Arabic letters are always connected to the following letter, whereas the remaining six are not. As a result, Arabic words can be broken into several visually distinct elements or sub-words (see Abandah & Khedher, 2009; Essoukri, Amara, & Bouslama, 2003): on average, Arabic words have 4.3 letters and 2.2 sub-words (Khedher & Abandah, 2002). For instance, the word (return; Ewdp, with the Buckwalter transliteration) can be decomposed into three sub-words ([p], [d], and [Ew]; note that the transliterations are written from left to right), the word (neck, rqbh) can be decomposed in two sub-words (and), while the word (closed, mglq) has all letters connected (i.e., it can be considered as a single sub-word). It has been suggested that, being visually distinct elements, sub-words in Arabic (e.g., [tr] and jb] in the word ترغب [trjb]) may represent an intermediate level between the letter level and the whole-word level in an interactive activation model (e.g., Belaïd & Choisy, 2006). Secondly, the shape of each letter may differ considerably depending on the location in the letter sequence (initial, middle, final, and isolated). For instance, the letter ع (‘ayin) adopts very different visual shapes when it is located in the initial letter position (e.g., _workers EmAl), in a middle position (e.g., _rate, mEdl), in the final position (e.g.,_ uploader rAfE), or when it is not connected to the neighboring letters (i.e., when it is presented in isolated form; e.g.,_ hungry people jyAE).

Given the complexity of Arabic orthography, it is not surprising that research on reading acquisition has revealed that learning to read in Arabic is slower than in another Semitic language with a comparable morphology, Hebrew (Azzam, 1984). Nonetheless, at the level of letter recognition Carreiras, Perea, and Abu Mallouh (2012) using a masked priming same-different matching task demonstrated that for adult readers there is fast access to abstract letter representations in Arabic. They found a repetition priming effect of similar magnitude for letters in which the middle and isolated forms are visually different (e.g., and are allographs of the letter ‘ayn) and for letters in which the middle and isolated forms are visually similar (and are allographs of zā’). This is the same pattern reported with Roman script in adult readers (e.g., a-A vs. i-I; Kinoshita & Kaplan, 2008). Although the Carreiras et al. (2012) findings do suggest that adult skilled readers have fast access to abstract letter representations, one should be cautious about generalizing data from isolated letter identification tasks to word identification tasks (e.g., see Blais et al., 2009).

A recent study on individuals with letter position dyslexia (i.e., a deficit in letter position coding) has suggested that visual form in Arabic might somehow be coded in hierarchically high levels of processing during visual-word recognition (Friedmann & Haddad-Hanna, 2012). Specifically, using a word naming task, Friedmann and Haddad-Hanna showed that three Arabic participants with letter position dyslexia (age range: 12-17) made a large number of letter transposition errors when the ligation/sub-word pattern was shared with a transposed-letter word neighbor: a word like تمهل slowed [tmhl] was often misread as its transposed-letter word neighbor تهمل neglect [thml]. On the contrary, the number of letter transposition errors was dramatically reduced when the ligation (i.e., the sub-word pattern) of the transposed-letter neighbor did not match: this was so, regardless of the changes in letter form (e.g., ترغب to want [tr jb], was not read as sunset تغرب [tjr b], and جهاز device [jhA z] was not read as جاهز ready [jA hz]). (We have added spaces in the transliterated examples to exemplify the changes in the ligation pattern.) Friedmann and Haddad-Hanna (2012) concluded that abstract letter identities in Arabic have an “indication of the form they appeared in". How can one reconcile this finding with the widespread assumption of highly abstract representations invariant for location, size, shape, etc. in the so-called "visual word form area" (see Dehaene et al., 2005; Grainger et al., 2008)? One potential option is to propose that there might be an intermediate level of sub-words between the letter level and the whole-word level during visual-word processing in Arabic (Belaïd & Choisy, 2006). In this proposal, orthographically similar words which share the same sub-word structure (e.g., تمهل slowed [tmhl] and تهمل neglect [thml]) would compete with each other by activating similar representations at the sub-word and whole-word levels (i.e., they would be perceptually confusable, especially if one assumes some "perceptual uncertainty" at assigning letter position; Davis, 2011; Gomez, Perea, & Ratcliff, 2008). In contrast, orthographically similar words with a different sub-word structure (e.g., ترغب to want [tr jb] and sunset تغرب [tjr b]) would be rather weak competitors.

Description of the experiments

In the present experiments, we examined whether the degree of visual information shared by prime and target (in terms the ligation pattern; see Friedmann & Hanna, 2012) modulates the magnitude of masked priming effects in Arabic with college-aged adults (university students) and developing readers (children of Grades 3 and 6). We focused on masked morphological priming rather than orthographically-related priming because previous reports on masked orthographic priming in Arabic failed to find a priming effect over an unrelated control condition (e.g., see Frost, Kugler, Deutsch, & Forster, 2005., 2005).

Arabic words can be decomposed into a three-letter (sometimes four-letter) consonantal root that conveys the basic meaning (e.g., ktb for marking/writing) and a word pattern. For each target word (e.g., كتاب book [ktA b], the root is ktb, the word pattern is --A-), we created two related pairs by replacing a letter from the word pattern. In the "visually similar" condition, the letter replacement kept the same ligation pattern as in the target word (the nonword كتزب [ktz b]; i.e., the three initial letters are ligated, whereas the final letter is presented isolated), while in the "visually dissimilar" primes the letter replacement prime altered the ligation pattern of the target word (the nonword كتخب [ktxb] has all the letters connected and it forms a unique sub-word). To obtain a measure of perceptual similarity for the related conditions, we followed the usual procedure of asking college students to rate the visual similarity of letters/words (see Simpson, Mousikou, Montoya, & Defior, in press, for a review of visual similarity matrices in literacy acquisition). Specifically, we asked sixteen students from the University of Valencia (all of them native speakers of Spanish with no knowledge of Arabic orthography) to rate on a 1–7 Likert scale the perceptual similarity, on a pair-wise basis, of the 66 Arabic pairs employed in the present experiments –half of the pairs kept the same sub-word pattern and the other half did not keep the ligation pattern. (Two lists of counterbalancing materials were created; 8 participants in each list.) As expected, results revealed that the pairs in which the pairs shared the ligation pattern (e.g., كتاب-كتزب [ktz b - ktA b]) were judged as more perceptually similar than those pairs which did not share the ligation pattern (كتاب-كتخب [ktxb -ktA b]) (5.0 vs. 4.2, respectively, $t > 5.8$, $p < .001$).

To make sure that a null difference between the two morphologically related conditions was not due to lack of processing of the primes, we included an unrelated nonword priming condition (e.g., كتاب-طيلر). Previous evidence with adult skilled readers in Arabic has consistently reported an advantage of primes that keep the consonantal root relative to unrelated controls (i.e., a masked morphological priming effect; e.g., Frost et al., 2005; Perea, Abu Mallouh, & Carreiras, 2010; Perea, Abu Malloh, García-Orza, & Carreiras, 2011; Velan & Frost, 2011).

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In the present experiments, we employed a go/no-go lexical decision task rather than the (more usual) yes/no-lexical decision task. The reason is that the go/no-go procedure produces faster responses, fewer errors, and less variability than the yes/no procedure in experiments with young readers (Moret-Tatay & Perea, 2011; see also Davis, Castles, & Iakovidis, 1998; Perea, Panadero, & Moret-Tatay, 2011, for evidence of masked priming effects with the go/no-go task.) As in previous experiments with orthographies in which there is no lowercase/UPPERCASE distinction, and to avoid visual continuity between primes and targets, primes were presented in smaller font size than the targets (see Perea et al., 2010, 2011; Velan & Frost, 2011, for a similar procedure).

The predictions are clear. If, as claimed by Friedmann and Haddad-Hanna (2012), visual form plays a relevant role in visual-word recognition in Arabic, one would expect a greater masked priming effect (relative to the unrelated control) for the morphologically related primes that keep the same ligation pattern as the target word (e.g., كتاب-كتزب [ktz b -ktA b]) than for the morphologically related primes that do not (كتاب-كتخب [ktxb -ktA b]). Alternatively, if the word's constituent letters are encoded abstractly at the early stages of processing, one would expect a similar masked priming (relative to the unrelated control primes) for the two types of morphologically related primes.

Experiment 1 (adult skilled readers)

Method

Participants—The adult participants were twenty-one undergraduate students at the Palestine University in Gaza. All of them were native speakers of Arabic and reported using Modern Standard Arabic every day. They had normal or corrected-to-normal vision.

Materials—The target words were 66 productive words in Arabic (40 of four letters and 26 of five letters). Given that the main experiment (i.e., Experiment 2) was designed to be conducted on a child population, these words were extracted from textbooks aimed at Grade 2 children. To verify that the words were known by the children, we asked 6 children, native speakers of Arabic, to read and tell the meaning of the words. We also presented the list of words to three primary school teachers to verify that the children would know the words. The final selection consisted in sixty-six words. The mean frequency of these words in the Aralex database was 34.3 per million (range: 0.23-343) (Boudelaa & Marslen-Wilson, 2010), and the mean number of orthographic neighbors was 6.7 (range: 0-18). Each target word was preceded by a nonword prime that was: 1) the same as the target except for the substitution of a non-root letter so that the ligation/sub-word pattern was unaltered (prime: كتزب [ktzb] and target كتاب book [ktAb]; the root is ktb); 2) the same as the target except for the substitution of a non-root letter –the same as above– so that the ligation pattern was altered (prime: كتخب [ktxb] and target book كتاب [ktAb]); or 3) an unrelated prime (e.g., طيلر [Tylr]). The list of the related prime-target stimuli is available at: http://www.uv.es/mperea/ArabicVisualForm.pdf. An additional set of 66 target nonwords of the same length as the target words (e.g., بناذ, لطكنف) was created for the purposes of the lexical decision task. The manipulation of the nonword trials was the same as that for the word trials. Three lists of materials were created, so that each target appeared once in each list, but each time in a different priming condition. Seven participants received each list.

Procedure—Participants were tested individually or in groups of two in a quiet room. DMDX software (Forster & Forster, 2003) was employed to present the stimuli and record the participants' responses. On each trial, a forward mask consisting of a row of hash marks was presented for 500 ms in the center of the monitor. Then the prime stimulus (in 24-pt traditional Arabic font) was presented and stayed on the screen for 50 ms (3 refresh cycles). The prime was followed immediately by the presentation of the target stimulus (in 36-pt traditional Arabic font). Mask, prime and target were presented in the same location. The target stimulus remained on the screen until the participants responded or until 2.5 sec had elapsed. Response times (RTs) were measured from target onset to the participant's response. Participants were instructed to press the yes [“ ”] button if the letter string was a 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. They were not informed of the presence of briefly presented stimuli. When asked after the experiment, none of them reported conscious knowledge of the existence of any briefly presented stimuli. Each participant received a different order of trials. Each participant received a total of 18 practice trials prior to the 132 experimental trials –the manipulation was the same as in the experimental trials.

Results and Discussion

Incorrect responses (0.4%) and RTs shorter than 250 or longer than 1,800 ms (0.4%) were excluded from the latency analyses. The mean correct lexical decision times and error percentages for the word targets are presented in Table 1. Analyses of Variance (ANOVAs) based on the participant and item mean correct RTs were conducted based on a 3 (prime-target relatedness: same ligation pattern, different ligation pattern, unrelated) × 3 (List: list 1, list 2, list 3) design. In this and subsequent experiments, List was included in the analyses as a dummy variable to partial out the variability due to the counterbalancing lists (Pollatsek & Well, 1995).

The ANOVA on the response times revealed a significant effect of prime-target relatedness, $\underline{F}1(2,36)=13.49$, $\underline{MSE}=459.0.6$, $\underline{\eta}^2=.55$, $\underline{p}<.001$; $\underline{F}2(2,126)=9.06$, $\underline{MSE}=2041.4$, $\underline{\eta}^2=.13$, $p<.001$. This effect reflected a priming effect (relative to the unrelated condition) for the pairs that had the same ligation pattern (32 ms; $\underline{F}1(1,18)=21.37$, $\underline{MSE}=518.4$, $\underline{\eta}^2=.54$, $\underline{p}<.001$; $\underline{F}2(1,63)=18.69$, $\underline{MSE}=1819.4$, $\underline{\eta}^2=.23$, $\underline{p}<.001$) and for the pairs that had a different ligation pattern (26 ms; $\underline{F}1(1,18)=14.01$, $\underline{MSE}=503.6$, $\underline{\eta}^2=.44$, $\underline{p}<.002$; $\underline{F}2(1,63)=8.45$, $\underline{MSE}=2304.2$, $\underline{\eta}^2=.12$, $\underline{p}<.006$). Importantly, there were no clear signs of any differences between the two related conditions (a 6-ms difference), $\underline{F}1(1,18)=1.27$, $\underline{MSE}=355.0$, $\underline{\eta}^2=.06$, $\underline{p}=.27$; $\underline{F}2(1,63)=1.01$, $\underline{MSE}=2000.6$ $\underline{\eta}^2=.02$, $\underline{p}=.32$.

The ANOVA on the error rates failed to reveal any effects, both $\underline{F}s<1$.

This go/no-go lexical decision experiment revealed a sizeable effect of masked morphological priming in Arabic, thus replicating earlier research with adult skilled readers using the yes/no procedure (Frost et al., 2005; Perea et al., 2010). More importantly, the magnitude of masked morphological priming was similar when the ligation/sub-word pattern of the prime and target was the same (e.g., كتاب-كتب) and when it was different (كتاب-كتيب) (32 vs. 26 ms, respectively). Indeed, only 11 of the 21 participants (52%) showed faster RTs for the pairs that shared the ligation pattern than for the pairs that did not share the ligation pattern. Therefore, the most parsimonious account is that, as occurs with skilled adult readers in the Roman script (Bowers et al., 1998; Bowers & Turner, 2005; Kinoshita & Norris, 2009), visually presented Arabic words are rapidly converted into abstract letter representations in the early moments of processing.

The critical question now is whether visual form plays a role with developing readers of Arabic. Experiment 2 was exactly the same as Experiment 1, except that the participants were a group of 3rd Grade and a group of 6th Grade readers. If the brain network from retinotopic representations to abstract representations were not completely settled in developing readers, one would expect an advantage of the related primes with the same ligation/sub-word pattern as the target over the related primes with a different ligation/sub-word pattern as the target, at least for the younger (Grade 3) readers. Alternatively, if

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developing (normal) readers have fast access to abstract letter representations, one would expect a pattern of data similar to that of adult skilled readers.

Experiment 2 (normally developing young readers)

Method

Participants—The participants were twenty-one 3rd Grade children (19 eight-year-olds and 2 nine-year-olds; 13 boys, 8 girls) and twenty-one 6th children (all of them eleven-year-olds; 11 boys, 10 girls) from a private Catholic school in Gaza. All the participants were native speakers of Arabic. All the teaching materials in the school were in Arabic except for the classes on English language. None of the participants had any sensory or neurological problems used as exclusionary criteria for learning disabilities. Two of the children had to be replaced because they did not follow the instructions (more than 40% of errors).

Materials and Procedure—These were the same as in Experiment 1.

Results and Discussion

Incorrect responses (5.0 and 0.7% for third and sixth graders, respectively) and response times shorter than 250 or longer than 1,800 ms (6.4 and 0.7% for third and sixth graders, respectively) were excluded from the latency analyses. The mean correct lexical decision times and error percentages are presented in Table 1. The statistical analyses were parallel to those of Experiment 1 except that “Grade” (Grade 3, Grade 6) was included as a factor in the ANOVAs.

The ANOVA on the response times revealed that Grade 6 children responded faster than Grade 3 children, $F1(1,36)=21.70$, $MSE=101726.9$, $\eta^2=.38$, $p<.001$; $F2(1,63)=755.0$, $MSE=6400.7$, $\eta^2=.92$, $p<.001$. In addition, there was a significant effect of prime-target relatedness, $F1(2,72)=8.99$, $MSE=1836.1$, $\eta^2=.20$, $p<.001$; $F2(2,126)=4.61$, $MSE=6507.1$, $\eta^2=.07$, $p<.015$, and this factor did not interact with Grade, both $Fs<1$. The relatedness effect reflected a robust morphological priming effect, relative to the unrelated control condition, for the targets preceded by a related prime with the same ligation pattern (35 ms; $F1(1,36)=14.64$, $MSE=1851.5$, $\eta^2=.30$, $p<.001$; $F2(1,63)=16.54$, $MSE=4816.0$, $\eta^2=.21$, $p<.001$) and for the targets preceded a related prime with a different ligation pattern (32 ms; $F1(1,36)=12.14$, $MSE=1824.4$, $\eta^2=.25$, $p<.008$; $F2(1,63)=7.80$, $MSE=7248.8$, $\eta^2=.11$, $p<.008$). As in Experiment 1, the RT difference between the two morphologically conditions (i.e., same vs. different ligation pattern) was very small a nonsignificant (a 3-ms difference), both $Fs<1$.

The ANOVA on the error data only revealed that Grade 3 children committed more errors than Grade 6 children, $F1(1,36)=8.15$, $MSE=67.62$, $\eta^2=.19$, $p<.008$; $F2(1,63)=41.9$, $MSE=41.38$, $\eta^2=.40$, $p<.001$.

The present experiment with normally-developing young readers successfully replicated Experiment 1. As expected, error rates in the masked priming lexical decision go/no-go task were reasonably low (see Perea et al., 2011), and RTs and error rates were lower for 6th Graders than for 3rd Graders (e.g., Acha & Perea, 2008; Castles et al., 2007). More important, the magnitude of the effect of masked morphological priming (around 32-34 ms) was not influenced by the visual similarity between prime and target. Indeed, only 23 out of 42 participants (54.7%) showed an advantage of the related condition that kept the same ligation pattern for primes and targets over the related condition that altered the ligation pattern.

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Taken together, the present data offer clear evidence to support the view that readers have fast access to a word's abstract letter representations over and above visual-word form. Nonetheless, one could argue that there could have been a ceiling effect in the morphologically related conditions. That is, access to the consonantal root might have produced a near-to-maximal priming effect. To rule out this possibility, it is necessary to show that an identity priming condition produces a substantial advantage over the morphological priming conditions. This was the goal of Experiment 3. Experiment 3 was a replication of Experiment 1 that included a new condition: the identity priming condition (e.g., كتاب-كتاب). If identification times to target words preceded by an identity prime are substantially faster than those preceded by a morphologically related prime, this would imply that the lack of differences between the two morphologically related priming conditions in Experiments 1 and 2 was not due to a ceiling effect.

Experiment 3 (Replication of Experiment 1 with an identity condition)

Method

Participants—The participants were thirty-two undergraduate and graduate students at the Universitat de València and the Universidad Politécnica de Valencia. All of them were native speakers of Arabic who had studied both primary and secondary education in Arabic-speaking countries. They reported using Modern Standard Arabic on a daily basis. All participants had normal or corrected-to-normal vision.

Materials and Procedure—The prime-target conditions were the same as in Experiments 1 and 2, except that we added a fourth priming condition: the identity condition (i.e., target stimuli could also be preceded by an identity prime). We used the same target stimuli (66 words and 66 nonwords) as in Experiments 1 and 2, except that for counterbalancing purposes, we added two new word pairs and two nonword pairs (68 word targets and 68 nonword targets; 17 items/condition). Four lists were created to counterbalance the prime-target pairs across the four priming conditions.

Results and Discussion

Incorrect responses (0.8%) and RTs shorter than 250 or longer than 1,800 ms (0.8%) were excluded from the latency analyses. The mean correct lexical decision times and error percentages for the word targets are presented in Table 1. Three planned comparisons were conducted to examine the critical effects under scrutiny. To examine the effect of visual form, we compared the two morphologically related conditions (i.e., same vs. different ligation pattern). To examine the existence of a morphological priming effect, we analyzed the difference between the two morphologically related conditions (as a whole) and the unrelated control condition. And, critically, to examine a potential ceiling effect in the morphologically related conditions, we analyzed the differences between the morphologically-related conditions (as a whole) vs. the identity condition

As in Experiments 1 and 2, there were no signs of any differences between the visually similar and the visually dissimilar related conditions (602 vs. 601 ms, respectively), both Fs < 1, and there was a robust morphological priming effect relative to the unrelated condition (a 25.5-ms difference), $F1(1,28)= 14.75$, $MSE=680.0$, $\eta^2=.35$, $p=.001$; $F2(1,64)= 9.31$, $MSE=2555.4$, $\eta^2=.13$, $p=.003$. More important, response times in the identity priming condition were, on average, 18.5-ms faster than the response times in the morphologically related priming conditions (as a whole), $F1(1,28)= 10.26$, $MSE=569.5$, $\eta^2=.27$, $p=.004$; $F2(1,64)= 9.03$, $MSE=1772.6$, $\eta^2=.12$, $p=.004$. Therefore, the lack of differences between the two morphologically related conditions cannot be attributed to a ceiling effect.

The statistical analyses on the error rates did not to reveal any significant effects, all Fs<1.

The present experiment replicated the critical findings from Experiments 1 and 2, and, furthermore, revealed a clear advantage (around 19 ms) of the identity condition over the two morphologically related conditions (see Frost et al., 2005, for a similar advantage [18 ms] of the identity condition over the morphologically related condition with adult skilled Arabic readers –note that Frost et al. did not control for the ligation pattern between prime and target). Although one might argue that it may be important to replicate this experiment with developing readers, previous research has shown that the magnitude of masked priming effects with developing readers (using the Roman script) is substantially greater for identity primes than for one-letter-different primes (e.g., see Castles, Davis, & Lechter, 1999). Indeed, there is something special about masked identity priming: masked identity priming (but not other types of priming) is robust when there is a masked intervening (unrelated) word between prime and target (see Forster, 2009). In sum, we can be confident that the lack of a modulating effect of visual similarity (in terms of ligation pattern) in Experiments 1 and 2 was not due to a ceiling effect in the morphologically related conditions.

General Discussion

This paper examined whether young readers have fast access to abstract letter representations during word processing in a very intricate orthography (Arabic). The results revealed that the magnitude of masked priming effects relative to an unrelated priming condition was remarkably similar when primes and targets kept the same (visual) ligation pattern (e.g., كتاب-كتزب [ktz b -ktA b]) and when primes and targets had different ligation pattern (كتاب-كتخب [ktxb -ktA b]) –note that, unsurprisingly, perceived visual similarity was substantially larger in the pairs with the same ligation pattern. The same pattern of data occurred for developing children (3rd and 6th Graders) and adult readers. Importantly, the lack of difference between the two morphologically related conditions was not due to a ceiling effect: words preceded by an identity prime were identified substantially faster than those preceded by a morphologically related prime (Experiment 3). This finding implies that participants were actually processing the prime's individual letters at an abstract letter level. Taken together, the present findings support the view that masked priming effects in Arabic occur at the level of abstract letter identities, thus extending the findings of Bowers et al. (1998) obtained with skilled readers in the Roman script to a child population in a more complex orthography (Arabic). The present study also generalizes the letter priming data reported by Carreiras et al. (2012) in Arabic with adult skilled readers to a word recognition task.

How does the cognitive system attain abstract codes in Arabic? As suggested by the Polk et al. (2009) model, some contextual cues may help generalize the different instances of the letters to a common shared representation. These cues may well be phonological, as proposed by Bowers and Michita (1998). By Grade 3, Arabic children may have learnt to associate the different allographs of the letters with the sounds. Simulation work using neural networks in Arabic would be necessary to examine this possibility –and how the teaching method may modulate this process. We should note that children start learning the Arabic letters when they are four/five years old. Thus, Grade 3 children have been exposed to print at a level such that the visual presentation of the masked primes can be rapidly converted into an abstract letter/word code. Nonetheless, it is reasonable to assume that, at the beginning of the process of learning to read, children may be more sensitive to the different letter forms in Arabic and that representations of the letter forms become more and more abstract as reading experience increases. Unfortunately, masked priming lexical decision data with Grade 1 or Grade 2 children are very noisy and the experiment would have little experimental power to detect a (presumably) small effect. An alternative option is to examine how adult learners of Arabic acquire abstract letter codes. Nonetheless, we must keep in mind that the processes underlying the formation of abstract letter codes in adult readers may differ from those of young readers. Future research should explore these possibilities.

What are the implications of the present data for a model of visual-word recognition in Arabic? There have been some suggestions that there should be an intermediate, sub-word level that would mediate between the letter level and the word level (e.g., Belaïd & Choisy, 2006). In this type of model, words that share the sub-words (e.g., تمهل [tmhl] and تهمل [thml]) would be closer in perceptual space than those words that do not share the sub-words (e.g., جهاز [jhA z] and جاهز [jAhz]). However, leaving aside that we failed to find any modulating effects as a function of the ligation pattern in the three experiments –which poses some problems for this proposal, there is evidence that perceptual space in Arabic is organized at morphemic level (e.g., see Frost et al, 2005; Perea et al., 2010, 2011). The consonantal root conveys the basic word meaning in Arabic, as in other Semitic languages. Given that the letters of the consonantal root may occur in different sub-words (e.g., as in the case of the consonantal root ktb in the word كتاب book [ktA b]), an intermediate level of sub-words could hinder rather than help the process of lexical access in Arabic.

As indicated in the Introduction, the data from Friedmann and Haddad-Hanna (2012) suggests that visual form might play a role in Arabic. In their study, Friedmann and Haddad-Hanna employed an untimed naming task with three individuals with letter position dyslexia in which only accuracy was recorded. We believe that the existence of fast access to abstract letter representations (as shown here) is not at odds with some role of visual form at some stage of processing –in particular with individuals with dyslexia. There are reports with the Roman script of an effect of overall visual shape with words in acquired dyslexic patients (see Howard, 1987) and in dyslexic children (see Lavidor, 2010). Thus, it is possible that in cases of developmental/acquired dyslexia, individuals may focus more on global, visual elements rather than on abstract letter representations –regardless of the script. Bear in mind that words may initially be processed at a visual, logographic level in the initial steps of learning to read (see Frith, 1985), and that this route might be operative under some circumstances. Indeed, there are computational models which assume some (small) role of visual form during word processing (e.g., E-Z Reader model; Reichle, Pollatsek, Fisher, & Rayner, 2008; see also the SOLAR model, Davis, 1999). Further research using a task that taps directly into the time course of letter (or word) processing in Arabic should shed more light on the apparent discrepancies between our data and those of Friedmann and Haddad-Hanna (2012) across different levels of reading skill in normal and clinical populations.

To sum up, despite the visual complexity of Arabic orthography, the present study has revealed that normally-developing young readers (3rd and 6th Graders) have access to abstract letter representations in the early stages of visual-word recognition, similarly to adult skilled readers. Further empirical/theoretical work is necessary to examine how the human cortex converts the visually presented items into abstract representations in orthographic systems as different as the Roman and Arabic scripts.

Acknowledgments

The research reported in this article has been partially supported by Grants CONSOLIDER-INGENIO2010 CSD2008-00048 and PSI2011-26924 from the Spanish Ministry of Economy and Competitiveness and Grant ERC-2011-ADG-295362 from the European Research Council. We thank Jeff Bowers and an anonymous reviewer for their very helpful comments on an earlier version of this paper.

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Table 1

Mean lexical decision times (in ms) and percentage of errors (in parentheses) for word targets in Experiments 1-3

	Prime-Target Relatedness					
	Identity	**Same Ligation**	**Different Ligation**	**Unrelated**	**Priming Unr-Same**	**Priming Unr-Different**
Experiment 1						
Adult readers		545 (0.2)	551 (0.4)	577 (0.6)	32 (0.4)	26 (0.2)
Experiment 2						
3^{rd} Graders		893 (5.2)	900 (4.1)	945 (5.4)	52 (0.2)	45 (1.3)
6^{th} Graders		642 (0.6)	641 (0.6)	661 (0.9)	19 (0.3)	20 (0.3)
Experiment 3						
Adult readers	583 (0.6)	602 (1.0)	601 (0.9)	627 (0.7)	25 (−0.3)	26 (−0.2)

Note: Error rates for nonword targets were 2.6 and 3.1 for adult readers (Experiments 1 and 3, respectively) and 9.4 and 7.8% for 3^{rd} Graders and 6^{th} Graders, respectively (Experiment 2).