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# Analysis of Letter Representation Using Latin and Arabic Scripts: A Masked Priming Study

**Julien Dirani[1] · Arne Dietrich[1]**

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**Abstract** Reading plays an essential role in our everyday lives. The aim of this study is to investigate how letters are represented in the brain using the unique characteristics of the Arabic language, which can be written with 2 different scripts. The hypothesis proposed is that the processing of script is sound based: Phonology is what determines letter identity. Using a forward-masked priming paradigm, we showed that Latin-script primes facilitated the recognition of subsequent Arabic-script targets which differed in orthography but shared phonology, thus suggesting a common level of phonological processing. In addition, semantic priming effects were controlled for. The findings thus confirmed our hypothesis and showed that letters that represent the same sound are processed similarly.

**Keywords** Psycholinguistics · Language · Arabic · Priming

## Introduction

It has long been understood that word recognition is reliant on the identification of letters as abstract units (Besner et al. 1984). That is, the visual aspect of letters is lost early in the processing and becomes irrelevant once letters are identified as abstract representations. This is supported by evidence showing that word processing is shape and case invariant (Besner et al. 1984; Bowers et al. 1998; Paap et al. 1984; Polk and Farah 2002). For instance, Chauncey et al. (2008) used the event-related potential technique to look at the N250, the P325, and the N400 and showed that pre-lexical and lexical processing is unchanged, regardless of the size and font of words.

The strict definition of a letter is "a character representing one or more of a sound used in speech" (Oxford Dictionaries 2016). But how are letters represented in the brain? Masked priming is one of the most used methods to answer questions about word representations. It

✉ Julien Dirani
julien.dirani@nyu.edu

1 Department of Psychology, American University of Beirut, P.O. Box 11-0236, Riad El-Solh, Beirut 1107 2020, Lebanon

involves the presentation of a visual mask (e.g. '#####') before or after the prime, and permits the analysis of automatic and strategy-free processing of words (Kouider and Dehaene 2007; Posner and Snyder 1975). Importantly, studies using this method have shown that priming is not affected by the shape of words (e.g. Bowers et al. 1998) and that phonological priming with forward masking has reliable effects (Lukatela et al. 1998).

The issue of determining the nature of letter representation in the brain has already been addressed in the literature. In one of the first studies on this topic, Brown et al. (1984) investigated the role of script in lexical representation. To do so, they used a priming paradigm in a lexical decision task, comparing the scripts used in Hindi and Urdu; two different scripts that are almost phonemically identical. They were the first research group to show a facilitation effect on reaction times to words when primed to the transcription in a different script. This meant that some information present in the primes was carried over inducing a facilitation on the reaction times to the targets. These findings opened the door to research investigating the neural representation of script, however, this early paper had important limitations. The long duration of the prime as well as the absence of a mask meant that there was no control for semantic priming which prevented from determining whether the effect was caused by phonology or semantics. In fact, despite being visually dissimilar, the prime-target pairs shared both their phonological and semantic contents, and without further investigation it was impossible to determine which of the two was responsible for the facilitation effects that were found. Nevertheless, the authors presented evidence that script processing stops at the perceptual level and it is semantics and phonology that determine the formation of lexical units.

Later studies built on these findings by introducing the use of a mask before the prime in order to minimize strategic factors and properly measure the automatic processes of language comprehension. Gollan et al. (1997) used a forward-masked priming paradigm to analyze Hebrew and English scripts and found a stronger translation priming effect for cognates than non-cognates. In other words, even when using a mask, translated primes that share phonological aspects with targets facilitated reaction times. Although phonology differs slightly between English–Hebrew cognates, the findings demonstrated that even when processed automatically and without the use of strategy, different scripts that represent the same sounds share at least some level of processing. Still, the authors did not explicitly control for semantic priming, and it is still possible that semantic processing confounded the results. That is, it cannot be determined whether the priming effect was caused by the shared phonology of the prime and the target or by their shared meaning. Chen et al. (2007) also used a non-masked priming paradigm, though with the Kanji and Hiragana scripts. While Kanji uses logographic characters, Hiragana is syllabic and, therefore, more transparent, meaning that the mapping of letters to sounds is more straightforward. They found semantic facilitation effects for lexical decisions of Kanji words when primes were in Kanji, and phonological facilitation when primes were in Hiragana. That is, only the script that focuses on phonology induced phonological priming and the logographic script gave rise to semantic priming only. It is worth noting that the use of a mask could have altered the results by measuring only automatic processes. It is likely that the semantic priming effects would have been weaker, or absent if a mask had been used. Nevertheless, the absence of phonological priming with the Kanji primes disputed the idea that word lexical access and semantic processing universally require phonology. Phonological processing might only be essential for the processing of scripts that focus on sounds, as opposed to logographic scripts for example. Rao et al. (2011) arrived at a similar conclusion by comparing the opaque Urdu script to the more phonology-focused script used in Hindi. Further, Pylkkänen and Okano (2010) showed that transliteration priming occurs even when targets are written an atypical script. In their masked priming experiment, they presented Japanese words that are usually written in Katakana, written in Hiragana. They showed a transliteration priming effect even when the targets were written in a script in which they usually never appear. This means that even though participants had never read the words in the atypical script, they still showed a phonological facilitation effect. Despite the unfamiliarity of the words, phonology was still strongly involved.

In recent years, Arabic has started to be written using a combination of Latin script and numbers in addition to its original Abjad alphabet. The new Latin version of Arabic (LA) allowed Arabic speakers, and more specifically Lebanese–English bilinguals, to have more flexibility in texting and text-based communication. The relevance to the current study is that the same sound is being represented with different symbols (e.g. 't' and 'ت', '7' and 'ح'), so that one word can be written using two different types of letters. The aim of the current study was to take advantage of this, using a forward masked priming paradigm with the Arabic language, in order to investigate the representation of letters. We set out to confirm that letters have a sound representation by showing that the phonological information present in one script can prime the response to the same word transcribed into a different script despite their visual dissimilarity. That is, we aim to show that the sole phonological information present in the prime can facilitate responses to the target. The fact that Arabic can be written in two different scripts that are both familiar to our sample of participants allowed us to use it to build on previous findings by showing a persistent effect of scripts as sound associations. In fact, the major advantage of Arabic is that the words written in either script would be familiar to Arabic–English bilinguals. Although there is no formal way to make sure that familiarity to both scripts is equal, this still contrasts to some extent with other studies that used a new script or an unusual representation of the words (e.g. Maurer et al. 2008) in which participants see some representations of words for the first time. Thus, the usage of two scripts that are both familiar to participants allowed us to maximize the ecological validity of the stimuli. The resulting stimuli were fully symmetrical and exactly matched in terms of language, their focus on phonology, and semantics. In addition, masked priming was used in order to control for strategies and to properly assess automatic processes. The fact that both scripts are used in the real world will significantly improve the ecological validity of the results. Finally, the design includes a semantic priming task in order to control for any effects that might be caused by the meaning of the words rather than their phonology.

## Methods and Procedures

### Participants

Twenty-four fluent Arabic–English bilinguals gave written consent to participate in the study (14 Females, Mean age = 20.4, Range = 18–23). All of them were undergraduate students from the American University of Beirut, right-handed, had normal or corrected to normal vision with no history of neurological or psychiatric disorders. None of them reported having any learning or reading disorder. Five out of the 24 participants were used to pilot the procedure and one of the participants dropped out of the study after completing the Arabic-script task. This resulted in a total of 19 participants for the Arabic-script subtask and 18 participants for the Latin-script subtask. All participants reported being familiar with both standard Arabic and Arabic written in Latin letters, although there was no formal way to operationalize these reports. The study received ethical approval from the American University of Beirut Institutional Review Board.

## Procedure and Experimental Task

An important assumption of this study was that Modern Standard Arabic (MSA) words are familiar to Lebanese Arabic–English bilinguals in both Latin and Arabic scripts. That is, we assumed that all word-stimuli were ecologically valid and that participants had already encountered them in the real world. However, LA is not an official language as it was originally developed out of convenience for usage on social media. Therefore, while we can safely assume that all participants are familiar with LA, it is impossible to control for the actual frequency of the words. It is possible that participants might encounter some LA words in our experimental procedure for the first time, and therefore not process them as automatically as Standard Arabic words. To ensure that participants had encountered all word-stimuli at least once outside the lab, we asked them to do a frequency judgment task 2 weeks prior to the main experiment. They had to rate how frequently they had read, written, or typed 152 MSA words (High, Medium, or Low) with half of the words written in LA and the other half in Arabic. Participants were instructed that their rating was script specific. The words consisted of the entire target words that were later used in the main experiment in addition to a few words that were added as fillers. The responses of the participants were not analyzed since the only purpose of this task was to expose the participants to the word-stimuli outside the lab.

Participants were then invited to come for the main experiment 2 weeks later. The reason for this delay was to avoid any confounding long-term priming effects. The main experiment consisted of a forward masked priming paradigm during a lexical judgment task. Participants were asked to give Yes/No responses via button presses with their right hand. They were not informed of the presence of primes, and were asked to answer as fast and accurately as they could. Half the target words were in Arabic script and the other half were in Latin script. Participants read all the target stimuli from one script then moved on to the other script, thus creating two subtasks for the experiment. The order in which participants did the 2 subtasks was counterbalanced. Each subtask was divided into 3 blocks and was preceded by a practice block. The order of the target words was random.

## Stimuli

All the stimuli were nouns in their root form (e.g. ورَقة, ارنب). Frequency and number of letters were controlled across all prime types and targets. It was important that the second language of participants be English (i.e. not another language that uses the Latin alphabet) in order to ensure that the transliteration to Latin be exact. For example, the letter 'و' would be transliterated to 'ou' in French and 'oo' in English. Thus, in order to ensure that our transliteration to LA was accurate, all participants were Arabic–English bilinguals. After the generation of the raw set of MSA words, three different volunteers did the transliteration into LA. Any word that was transliterated differently at least once was eliminated from the set. Ten undergraduate students from the American University of Beirut then volunteered to do the second judgment of the transliteration. The words were presented to them in LA and they were asked to mark a word if they could not understand it or if they would have written it differently. All the marked words were then eliminated from the set. This was done to make sure that the words would be read and pronounced similarly across

**Table 1** Example stimuli for Arabic targets

| Target words | |
|---|---|
| Target | شَجَرَة |
| Primes | |
| Semantic | غابة |
| Repetition | شَجَرَة |
| Unrelated | أُغنِيَة |
| Script change | shajara |
| **Non-words** | |
| Target | جَشَتَر |
| Prime | shams |

Each target is repeated 4 times, once with each prime type

**Table 2** Example stimuli for Latin targets

| Target words | |
|---|---|
| Target | shajara |
| Primes | |
| Semantic | ghaba |
| Repetition | shajara |
| Unrelated | oghniya |
| Script change | شَجَرَة |
| **Non-words** | |
| Target | jarasha |
| Prime | شمس |

Each target is repeated 4 times, once with each prime type

participants, since there is no official spelling for LA. Finally, diacritics were included for all the MSA words to perfectly match the phonology when transliterated into LA.

For each subtask, participants saw 392 stimuli (176 words, 216 non-words) for a total of 784 stimuli for both tasks. In addition, each practice block included 28 stimuli (14 words, 14 non-words). Only responses to the words were included in the analysis. For each of the 2 subtasks, the word-stimuli consisted of 44 sets of prime-targets (See Tables 1, 2). The target word was repeated 4 times within a set, while the prime took 4 different types: Repetition, script, semantic, and unrelated. (1) The repetition prime was identical to the target. (2) The unrelated prime was different from the target in all aspects (visual, phonology, and semantics). These 2 primes served as baselines to check for the strongest (i.e. repetition) and weakest priming effect (i.e. unrelated). (3) The script change prime was the same word as the target but written in the different script. That is both words shared the same phonology and semantics, but the visual input (i.e. the script) was different. Finally, (4) the semantic prime was semantically related to the target but did not share visual or phonological aspects with it. We expected that if script has a sound identity, priming should occur in the script change condition. The short duration of the prime (47 ms) as well as the usage of a forward mask allows controlling for any semantic priming that might occur (Rastle et al. 2000). For each subtask, the non-word condition consisted of 216 prime-target pairs where the target was a non-word and the prime was a word written in the script different from that of the non-word target. All non-words were created by switching around the letters of the target words randomly in order to match character frequency across the words and non-words. Some exceptions were made for the non-words written in Arabic script by adding random letters to some non-word. This is because some 3-letter Arabic words still make sense regardless of the order of the letters.

Stimuli presentation was done with E-Prime 2.0 software (Psychology Software Tools 2012) in the following sequence: First, a forward mask (#####) was shown for 500 ms followed directly by the prime for 47 ms. The literature suggests that this prime duration is short enough to remain invisible to the participants (Kouider and Dupoux 2005). The target stimulus was then presented on screen until the response was given. Inter-trial intervals lasted 500 ms in which a fixation cross was shown at the center of the screen (See Fig. 1).

## Results

All participants reported being unaware of the presence of primes. Post-hoc inspection of the stimuli showed that 2 sets of the Latin subtask contained adjectives (walad-; رخيص 3ameeq-واسع). These sets were excluded from the analyses resulting in 42 analyzed sets for the Latin subtask (168 trials) and 44 sets for the Arabic subtask (176 trials). Accuracy scores (in %) and reaction times (in milliseconds) were analyzed. Accuracy scores were generally high for both subtasks (Arabic targets: Mean = 98%, Latin targets: Mean = 96%), which indicates that participants understood the task and performed it without difficulty. Participants were significantly more accurate with Arabic targets (Mean = 98.07, SD = 2.25) compared to LA targets (Mean = 96.34, SD = 5.82) ($t(71) = -2.46$, $p < .05$). For the Arabic targets, mean accuracy scores were respectively 97.73% (SD = 3.03), 98.33% (SD = 2.12), 98.09% (SD = 1.74), and 98.09% (SD = 2.04) for the repetition, script change, semantic, and unrelated conditions. A repeated-measure ANOVA showed no significant main effect of prime type on accuracy scores ($F(3, 54) = 0.35$, $p = .786$). For the Latin targets, mean accuracy scores were respectively 95.71% (SD = 6.56), 96.34% (SD = 7.19), 97.09% (SD = 4.86), and 96.21% (SD = 4.68) for the repetition, script change, semantic, and unrelated conditions. A repeated-measure ANOVA showed no significant main effect of prime type on accuracy scores ($F(3, 51) = 1.04$, $p = .385$).

For the reactions times (RTs) both by-subject and by-item analyses were conducted. RTs were analyzed using a repeated-measure ANOVA with prime type as the independent variable. Incorrect trials and trials with RTs larger than 1000 ms or smaller than 300 ms were considered outliers and were excluded from the analysis (122 (3.72%) of Arabic trials, 221 (7.24%) of Latin trials) (Grainger et al. 1991; Grainger, 1998). On average,

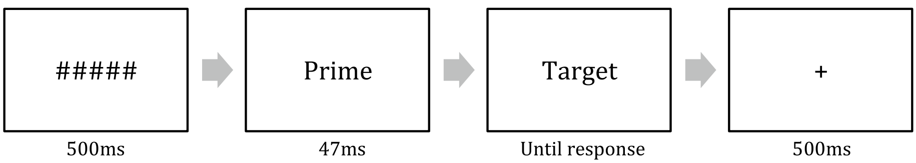


**Fig. 1** Trial presentation. Time on screen is indicated below the frames, in milliseconds

participants were faster to respond to Arabic (Mean = 596.85, SD = 57.09) than to Latin targets (Mean = 636.76, SD = 58, 20) (t(71) = 4.88, $p < .001$) which implies that they were not equally proficient in both scripts.

For the Arabic targets, the by-subject analysis showed that there was a significant main effect of prime type (F(3, 54) = 38.95, $p < .001$). Post-hoc tests using the Bonferroni correction revealed that the fastest reaction times occurred for the repetition primes (Mean = 561.38, SD = 53.09, $p < .001$ compared to the semantic and unrelated primes, $p = .002$ for script change). The script change condition (Mean = 592.38, SD = 55.45) showed significantly faster reaction times compared to the semantic (Mean = 620.64, SD = 52.21, $p = .004$) and unrelated primes (Mean = 621.67, SD = 47.58, $p < .001$). Finally, reaction times for the semantic and unrelated primes did not significantly differ ($p > .99$). The by-item analysis showed a similar pattern of results. There was a significant main effect of prime type (F(3129) = 56.411, $p < .001$). Post-hoc tests using the Bonferroni correction revealed that the fastest reaction times occurred for the repetition primes (Mean = 560.59, SD = 36.78, $p < .001$ compared to the semantic, unrelated, and script change primes). The script change condition (Mean = 590.61, SD = 30.49) showed significantly faster reaction times compared to the semantic (Mean = 620.23, SD = 35.29, $p < .001$) and unrelated primes (Mean = 620.53, SD = 34.51, $p < .001$). Finally, reaction times for the semantic and unrelated primes did not significantly differ ($p > .99$).

For the Latin targets, the by-subject analysis showed a significant main effect of prime type (F(3,51) = 20.67, $p < .001$). Post-hoc tests using the Bonferroni correction revealed that the fastest reaction times occurred for the repetition primes (Mean = 607.72, SD = 59.49, $p < .001$ compared to the semantic and unrelated primes, $p = .037$ compared to script change). Although the script change condition (Mean = 634.90, SD = 58.29) was faster than the semantically related condition (Mean = 649.83, SD = 48.90) and unrelated condition (Mean = 654.63, SD = 58.33), these results were not significant (respectively, $p = .249$, $p = .085$). Finally, the unrelated and semantically related conditions were not significantly different ($p > .99$). The by-item analysis also showed a significant main effect of prime type (F(3123) = 21.08, $p < .001$). Post-hoc tests using the Bonferroni correction showed that the repetition prime condition was once again the fastest (Mean = 607.20, SD = 44.35, $p < .001$). While the script change condition (Mean = 634.60, SD = 36.24) showed significantly shorter RTs compare to the unrelated condition (Mean = 655.13, SD = 44.34, $p < .05$), it did not significantly differ from the semantically related condition (Mean = 649.06, SD = 35.84, $p = .254$). Finally, the semantically related and unrelated conditions did not significantly differ ($p > .99$).

To sum up, for the Arabic task we found a significant priming effect when comparing the script change condition to the unrelated condition (By subject: 29.29 ms; by item: 29.92). As expected, there was also a strong priming effect for the repetition primes compared to unrelated primes (By subject: 60.29 ms; by item: 59.94 ms). Crucially, there was no effect of semantic priming. These results failed to fully replicate when Latin targets were used (See Fig. 2 for summary of RTs).

## Discussion

The current study set out to analyze the nature of the representation of script. Using a forward-masked priming paradigm, we took advantage of the usage of 2 different scripts for Arabic in order to assess the phonological identity of letters. We found that primes

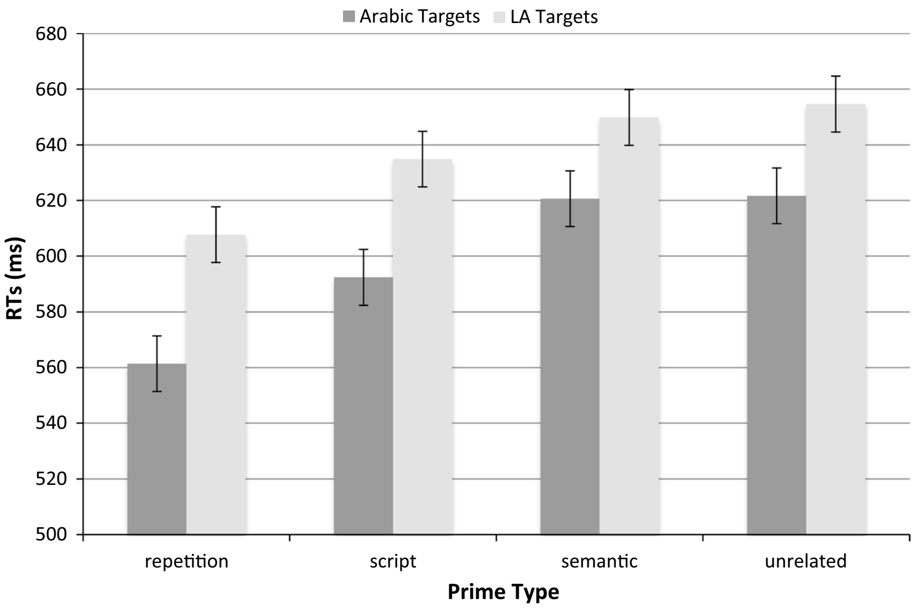


**Fig. 2** Summary of reaction times (in milliseconds)

written with the Latin script have a facilitation effect on the processing of the same words in the Arabic script, however this effect was not replicated when the primes were in Arabic and the targets were in Latin letters. As predicted, the semantic prime condition with Arabic targets showed that there was no priming effect at the semantic level, which means that the script change priming was caused by an aspect of the priming word that was processed pre-semantically. In other words, the absence of a facilitation effect with the semantically related primes confirmed that the semantic contents of the primes were not accessed, and that any priming effects that would have appeared in other conditions would be caused by pre-semantic aspects of the prime. It might be surprising that semantic priming did not occur in a lexical decision task, however, the very short duration of the prime, as well as the usage of a forward mask in the current design justifies the absence of any semantic priming. In fact, 47 ms is too short for semantic processing to occur (Rastle et al. 2000; Longtin et al. 2003; Rastle et al. 2004) and the presence of the mask ensures that the prime is not consciously accessible to participants, further reducing the possibility that some semantic processing can occur retrospectively once the prime disappears from the screen. In addition, the target appears on screen right after the prime, which makes it even less likely to process the semantics of the prime retrospectively. Only with the absence of a mask, and with a longer prime duration can semantic priming occur. In the script change condition, the only shared features between the prime and the target are the phonology and the semantics; the visual aspect being different. Thus, by eliminating the possibility of semantic priming, we can conclude that it is the phonology that is responsible for the facilitation effect found in the script change condition when the targets were in Arabic. Once again, we could not reach the same conclusion when the targets were in Latin, since the script change condition gave no priming effect (i.e. similar RTs compared to the unrelated condition). Moreover, we can completely rule out the possibility of visual priming. In the script change condition, there are no similarities in the visual aspect of the prime and the target. The two Arabic scripts use different alphabets with completely different shapes. Arabic also uses attached letters as opposed to the Latin script. This strengthens the findings by showing that the priming effects of the script change condition had no possible confound of visual priming.

Chen el al. (2007) showed that with a script that focuses on phonology (Hiragana), phonological priming occured, but not when using a logographic script. In Arabic, the focus on phonology changes depending on whether diacritics are included or not, since diacritics force the reader to focus on sounds. In the current study, diacritics were included in order to create a perfect phonological match between the Latin and Arabic stimuli. Since Latin letters have a very transparent phonology and have clearly depicted vowels, we included diacritics in order to have a symmetry between the phonology of the Latin and Arabic words. Arguably, adding diacritics forced participants to focus on phonology, however that was done in order to equalize the phonological focus on Latin and Arabic thus resolving the asymmetrical phonological representations of the two scripts. By making the Arabic words more transparent we were able to compare two stimuli that share the same language, script, and phonology. The only difference being script and all other things being equal, we were able to show that the neural value of script stops at the perceptual level, and acquires a phonological identity, at least in sound-based alphabets. Further, including diacritics was essential for phonological disambiguation. All participants were Lebanese Arabic speaker who were instructed that the words were written in MSA. If diacritics were not included we would have no way to explicitly control for dialect, and participants could have still read the words in Lebanese Arabic. Lebanese Arabic having a different phonological interpretation of words, the Latin transcription would not have matched the Lebanese Arabic version of words. For example, if participants read طاولة in Lebanese Arabic, the Latin transcription would be “tawla” compared to the MSA transcription “tawila”. Since phonological disambiguation was crucial for the experimental design, we included diacritics to control for the match between Arabic words and their Latin transcription.

We were able to show a script change priming effect when the targets were in Arabic, but found no effects when the targets were in Latin. In fact, the by-subject analysis with LA targets showed that none of the conditions other than the repetition significantly differed from the unrelated condition. It can be argued that since participants were significantly slower and less accurate to respond to LA compared to Arabic words, there could have been a ceiling effect in RTs that concealed any priming effects that might have occurred. That is, participants being too slow to respond to LA targets, unconscious priming effects driven by anything more than simple sensory input could have been too weak to show any significance over and above the longer response times. This could explain why only the repetition primes consistently showed faster responses with LA targets, which was an effect of pure visual priming. Since the by-item analysis did show that the script change condition was faster than the unrelated condition, it is likely that increasing the power might eventually give a similar pattern of result for the Latin targets as for the Arabic targets. However, participants did show a phonological priming effect with Arabic targets when the primes were in LA, which means that higher level processing (i.e. higher than simple visual input) did happen to some extent even for LA words. Thus, the current explanation for a lack of effects with the LA targets in its simple form fails to reconcile these seemingly contradicting findings. More research will have to be done on the time course of processing of LA to fully understand the issue at hand. For example, a similar experiment could be conducted where familiarity and frequency of script are formally controlled for in order to see whether they truly modulated the script change priming effect.

In conclusion, we showed that Arabic words are processed in a similar manner regardless of the script used. This is the case because phonology is accessed pre-semantically and processed regardless of the visual form the script takes. These findings support previous studies showing that word processing is script and shape invariant (Besner et al. 1984; Bowers et al. 1998; Polk and Farah 2002; Pylkkänen and Okano 2010). Accordingly, sounds are not linked to specific scripts; rather, letters representing the same sound are processed similarly, regardless of script. True to their definition, letters are therefore representations of sounds. In short, our study showed that letters have a phonological representation. Finally, by looking at Latin and Abjad script, our findings add a cultural and cross-linguistic input to the existing literature where little work is done with the Arabic language.

The bigger question that has to be asked regards how two completely different visual inputs become a similar unit of meaning. Analyzing the effects of primes on word processing was the first step in assessing whether 2 words written in different familiar scripts have any shared processing. The proposed idea is that letters are processed as sounds before moving up the hierarchy to undergo semantic processing. Two identical words written in different scripts are thus processed as the same phonological information before being processed further. More research has to be done to further analyze this proposition by looking at the specific time-course of the processing of words written in different scripts. Some advances in this direction have already been made (e.g. Pylkkänen and Okano 2010). Future research could also examine whether removing the diactrics would affect the phonological priming effect.

A limitation worth mentioning is the possibility of a long-term repetition priming effect. In fact, each target word appears 4 times, each time with a prime from one of the 4 conditions. While there definitely is some level of priming due to repetition, we argue that the effect found when comparing the condition of interest (i.e. script change) to the unrelated is large enough to outweigh the much smaller repetition effects. Indeed, the values found with the Arabic targets are considered moderate to large and are strong enough to confidently assume that the effects due to our manipulation are indeed significant. Furthermore, the randomization used for the stimuli presentation averages out any long-term repetition priming effect. Thus, while there could be some level of confounds due to repetition of stimuli, the results we found accurately illustrate the effects of our experimental manipulation.

**Compliance with Ethical Standards**

**Conflict of interest** The authors declare that they have no conflict of interest.

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