

# Transposed Letter Priming Effects and Allographic Variation in Arabic: Insights From Lexical Decision and the Same–Different Task

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Reading is resilient to distortion of letter order within a word. This is evidenced in the “transposed-letter (TL) priming effect,” the finding that a prime generated by transposing adjacent letters in a word (e.g., *jugde*) facilitates recognition of the base word (e.g., *JUDGE*), more than a “substituted-letter” control prime in which the transposed letters are replaced by unrelated letters (e.g., *junpe* -*JUDGE*). The TL priming effect is well documented for European languages that are written using the Roman alphabet. Unlike these languages, Arabic has a unique position-dependent allography whereby some letters change shape according to their position within a word. We investigate the TL priming effect using a lexical decision (Experiment 1) and a same–different match task with Arabic words (Experiment 2) and nonwords (Experiment 3). No TL priming effects were found in Experiment 1, suggesting that the lexical-decision task engages lexical access processes that are sensitive to the Semitic nonlinear morphological structure. Experiments 2 and 3 revealed a robust TL priming effect overall. Nonallographic TL primes produced significantly larger facilitation than allographic TL primes, indicating that Arabic readers use allographic variation to resolve the uncertainty in letter order during the early stages of orthographic processing. The implication of these results for current letter position coding models is discussed.

### **Public Significance Statement**

Transposed-letter (TL) priming effects are popularly interpreted as reflecting noisy perception of letter order. The Arabic writing system has a unique allographic feature whereby a letter’s shape and letter spacing depend on its position within a word. We show that TL priming effects for Arabic words and nonwords are modulated by allography in the same–different task. It is important to consider which unique property of the language/writing system produces the cross-language variation, and how it does so.

*Keywords:* TL priming, Allography, same-different matching task

Much of the recent cognitive and neurocognitive research on reading has come to focus on the front end of the mechanisms underpinning visual word recognition, namely the recognition of

letters comprised by a word (e.g., Bick, Goelman, & Frost, 2011; Dehaene, Cohen, Sigman, & Vinckier, 2005; Gómez, Ratcliff, & Perea, 2008; Grainger, Rey, & Dufau, 2008; Norris & Kinoshita,

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This research was funded by two UAEU-FHSS grants to Sami Boudelaa (FHSS22201 and G00001813), and by grant SUAG/012 from the Medical Research Council, United Kingdom to Dennis Norris.

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2012a). Three issues are at the center of this research. The first relates to the existence of abstract letter representations and how these serve as targets for the visual input perceived during reading. The second concerns the way in which information about letter order is coded, and the final issue relates to whether different languages bring different constraints to bear on the question of letter abstractness and letter-order coding.

Words can be written in letters of different sizes, different fonts, and different cases. Does this low-level perceptual variation play a role in reading or do the representations that drive lexical access abstract over these perceptual variations? From studies using the masked priming paradigm (Forster & Davis, 1984) there is now a wealth of evidence that reading is mediated by abstract letter representations. In this paradigm, a prime is presented briefly (typically 30–60 ms) following a forward mask consisting of uninformative hash signs and backward masked by the target to which an overt response is required. Responses to the target are facilitated when the prime is related to the target. Using masked priming with a lexical-decision task, Bowers, Vigliocco, and Haan (1998) showed that lowercase primes that were visually dissimilar to the targets presented in uppercase (e.g., *edge-EDGE*) yielded comparable facilitation effects to those produced by lowercase primes that were visually similar to their targets (e.g., *kiss-KISS*). This result has been taken as evidence that the letter representations supporting visual word recognition are abstract. Kinoshita and Kaplan (2008), and Kinoshita and Norris (2009) extended this finding to single letters and nonwords showing that the involvement of abstract letter representations is not specific to reading words. They used the same–different matching task in which a reference stimulus is presented in advance of the prime-target sequence and the subject's task is to decide whether the target is the same as or different from, the reference. The size of priming did not differ between visually similar prime-target pairs (e.g., *c/C*, *x/X*) and visually dissimilar pairs (e.g., *b/B*, *e/E*).<sup>1</sup>

The second issue concerns how letter order is coded. Recent research has amassed considerable empirical evidence showing that readers can cope with violations in the canonical order of letters in a word. This claim is supported by the phenomenon called the transposed-letter (TL) priming effect. This refers to the finding that a nonword prime constructed by transposing two adjacent word-internal letters (e.g., *jugde*) facilitates the recognition of the base word (*JUDGE*) more than a substituted-letter (SL) control prime in which the transposed letters are replaced by unrelated letters (e.g., *junpe*; e.g., Perea & Lupker, 2003). As with the data showing evidence for abstract letter identities, TL priming effects are also found with nonword targets in the same–different match task (Kinoshita & Norris, 2009). According to the noisy position view (Gómez et al., 2008; Norris & Kinoshita, 2012a), TL priming effects reflect the uncertainty in letter order arising from noise in the early stages of visual perception. Specifically, within the brief time that the prime is presented, the spatial order of neighboring letters in a letter string is ambiguous (i.e., it is uncertain whether *g* in *jugde* is to the left or right of *d*). To the extent that there is some possibility that 'd' precedes 'g,' the TL prime *jugde* will match *JUDGE* to a greater degree than the control prime *junpe*.

The evidence from the research summarized above strongly suggests that the visual word recognition system operates with abstract letter representations and that it shows a degree of toler-

ance in the processing of letter order. Most of this evidence has come from European languages that are written using the Roman alphabet. This brings us to the third issue driving research into visual word recognition, which relates to whether the structural characteristics of different languages can influence theorizing about the nature of the representation of letters subserving the reading process. Previous cross-linguistic research strongly suggests that typologically different languages not only organize their lexical spaces differently, but they also seem to weight different domains of linguistic knowledge differently (e.g., Frost, 2012 for Hebrew; Lee & Taft, 2011 for Korean). More specifically, it has been claimed that reading in languages like Hebrew and Arabic is subject to an extreme letter-coding scheme such that transposing the letters of a prime item does not generate the strong facilitation of target recognition typical in Indo-European languages. This claim is mainly based on the consistent absence of Transposed Letter (TL) priming in lexical decision with Hebrew (e.g., Velan, Deutsch, & Frost, 2013; Velan & Frost, 2009, 2011), and Arabic (e.g., Perea, Abu Mallouh, & Carreiras, 2010), which contrasts sharply with the facilitatory effects found in languages written in the Roman alphabet. What is the origin of this cross-linguistic difference?

As we will see in more detail below, written Arabic has two unique features that distinguish it from European languages written in the Roman alphabet: One is its Semitic morphological structure, the second is its extensive position-dependent allography. There are reasons to suspect that these two features may operate at different levels or stages of visual word recognition, and for this reason we will use two tasks that are differentially sensitive to stages of orthographic and lexical processing. Specifically, in the first experiment, we use the lexical-decision task to engage lexical processing and to confirm the absence of the TL priming effects in this task, as has been reported consistently with Semitic languages. This experiment also serves to validate our stimuli. We then use these stimuli in the same–different match task, in which the orthographic priming effects have been shown to operate at the level of prelexical orthographic representations consisting of abstract letter identities (Kinoshita & Norris, 2009; Kinoshita, Gayed, & Norris, 2018), and to be insensitive to morphological structure in European languages written in the Roman alphabet (Duñabeitia, Kinoshita, Carreiras, & Norris, 2011). Specifically, we focus on the orthographic system of Modern Standard Arabic (MSA), with its unique characteristics, to investigate whether the TL priming effect, which has been used as the main marker of letter order coding flexibility, is modulated by allographic variation. In what follows, we briefly present the key characteristics of the MSA orthographic system, then we summarize previous experimental research that addressed orthographic processing in Arabic.

### The MSA Orthographic System

The MSA orthographic system (see Daniels, 2013) operates with 28 letters that are written cursorily from right to left. From the

<sup>1</sup> In this task, masked priming effects are limited to the Same response and not observed with the Different response. Readers are referred to our previous works (e.g., Kinoshita & Norris, 2009, 2010; Norris & Kinoshita, 2008) for an explanation.

visual point of view, these letters fall into nine groups as shown in Table 1.

Groups 1 to 8 consist of letters with exactly the same base shape save for the presence of dots. Thus in Group 1, for instance, the three letters share the same base shape, but differ with respect to the number and position of dots, with in particular, the letter ب /b/ exhibiting a single dot underneath it, while the ت /t/, and ث /θ/, respectively, feature two and three dots above them. The exception to this pattern is the 10 letters of Group 9 which have unique shapes that they do not share with each other or with any other letter.

A number of orthographic characteristics make MSA an ideal writing system to investigate the issues of abstract letter representations and letter order coding. One relates to the allographic nature of the script whereby each letter can take as many as four different shapes depending on its position within the word: an initial, a medial, a final, and an isolated form as illustrated in Table 2.

Two variables interact to determine which allograph is used for a given letter. These are the position of the letter in the word, initial, medial, or final, and the presence or absence of a ligature with the preceding letter. Twenty-two of the 28 letters are fully ligating letters (i.e., they connect to the preceding and the following letter) and have four allographs, whereas the remaining six are partially ligating letters (i.e., they ligate only to the preceding letter) and have only two allographs each.

One consequence of the interaction of these two variables is that besides triggering changes in the form of a letter (e.g., لعب – لعب\*<sup>2</sup> ‘play’), allography manifests itself in two other ways. First, it can appear as a change in ligation pattern as in أفشلنا – أفشلنا\* ‘fail,’ where the underlined letter changes from a letter ش that ligates to the left and right to a ش ligating only to the left. Second, allography can show up as a redistribution of blank-spaces within the word. For instance, the blank space (indicated by the underscore here for ease of illustration) comes after the second letter in ولد *birth*, but after the third letter in the transposed nonword دملو. Importantly, although change in ligation patterns can occur without redistribution of blank spaces within the word (e.g., ألهم – ألهم\* ?lhm-?lhm ‘inspiring’), the reverse is not true in the sense that the redistribution of blank-spaces is always accompanied by a change in ligation patterns (e.g., أذب – أذب\* ?δhb-?hδb ‘going-civilize’) a change in letter form (e.g., أعم – أعم\* ?ʕlm-?ʕlm ‘inform-uncle’) or both (e.g., أعمد – أعمد\* ?ʕdm-?ʕmd ‘execute-intend’). Furthermore, a change in letter form does not necessarily trigger a blank-space redistribution and vice versa. In the transposed letter item يتطلعان\* the shape of the letters has changed compared with the original form يتطلعا ‘look forward to,’ but the blank space remains in the

Table 1  
Arabic Script and Letter Groups

Groups	Example	Groups	Example
1	ب /b, t, θ/	5	ش /s, ʃ/
2	خ /ħ, x/	6	ض /s <sup>ʕ</sup> , d <sup>ʕ</sup> /
3	ذ /d, ð/	7	ظ /t <sup>ʕ</sup> , d <sup>ʕ</sup> /
4	ز /r, z/	8	غ /ʕ, ɣ/
9	أ ي و ه ن م ل ك ق ف		

Note. Stimuli are given in Arabic and in Buckwalter transliteration with the manipulated root letters in upper case.

Table 2  
Fully and Partially Ligating Letters

Ligature	Initial	Medial	Final	Isolated	IPA
Full	غ	غ	غ/ع	غ	ɣ
Partial	د	د	د/د	د	d

Note. The Final letter column shows the allographs for the letter preceded by a nonligating and a ligating letter respectively.

same position, after the sixth letter, in both items. For the present purposes, we have opted to treat the three manifestations of allography as equivalent. We do this for two reasons, first, because a change in the form of the letter, a change in its ligation pattern, or the redistribution of blank spaces within the word may provide equally important cues about the identity of the letters within the orthographic string, and about its length, and second, because we are interested in the change in the overall shape of the word, which is equally apparent when the shape of the letter or its ligation pattern changes, or indeed when the blank spaces within the word are redistributed. In addition to this, the constraints we had to observe when building the experimental materials made it impossible to covary for instance letter-form change and ligation change without creating an existing root, which we strove to avoid. We will nevertheless consider the potential contribution of the different forms of allography in our post hoc statistical analyses.

In sum, the critical feature of MSA is that allography, in all its manifestations, is highly informative with regards to letter position in two important ways. First, when a reader sees the allograph ع, for instance, they know that it is neither at the beginning nor end of the word, whereas seeing the allograph غ is an unequivocal cue that it is at the end of the word. Second, the different allographs of a letter can affect the location of blank spaces within the orthographic sequence especially when the letter is nonligating. Note for instance that the blank space, indicated by an underscore, after the third letter, in the base word تجربة *tjr\_bt* ‘experience’ appears after the second letter in the transposed nonword version ترجة *tr\_jbt*. The sort of information conveyed by the various forms of the letters in MSA and the accompanying redistribution of the location of blank spaces in the orthographic sequence are qualitatively very different from the allography in the Roman script (uppercase and lowercase letters) which neither depends on letter position nor alters the location of blank spaces within a word.<sup>3</sup> Against this background, the question we address here is whether readers of MSA can take advantage of the order constraints provided by the position-specific allographs, or instead rely entirely on a more abstract level of letter representation that discards the allographic detail.

Another equally important feature of MSA orthography is that it is a predominantly consonantal system all of whose letters represent consonant phonemes except for three, known as *matres lectionis*, which serve to indicate the three long vowels of the language /aa, uu, ii/. The remaining three short vowels /a, u, i/ have no corresponding letters; instead they are written as diacritical marks above or below the letter. This characteristic of the script is

<sup>2</sup> The asterisk is used to indicate a nonword.

<sup>3</sup> In most languages the Roman upper-case letters can only appear as the first letter in a sentence or the first letter in a proper noun.

intimately linked to the Semitic morphological system which relies on a clear distinction between two morphemes: the root, typically made up of three consonants, and the word pattern (WP) essentially made up of vowels and a subset of consonants. The root provides constraining semantic information and plays an earlier and more durable role in the lexical access process than the word pattern which is interleaved with the root and conveys morpho-syntactic and phonological information, affecting the processing dynamics only during a limited time window (Boudelaa & Marslen-Wilson, 2005). Given the salience of the consonantal root as an access and representational unit in lexical processing in Arabic (Boudelaa & Marslen-Wilson, 2004, 2005, 2011, 2015), the question arises of how the transposition or substitution of root consonants modulates TL-priming effects.

### Previous Research on Orthographic Processing of Arabic

Perea et al. (2010) and Carreiras, Perea, Gil-López, Abu Mallouh, & Salillas (2013) have spearheaded research into letter order coding and abstract letter identities in Arabic. Using both lexical (lexical decision) and nonlexical (same-different matching) tasks, these authors have collectively made two important claims. One is that the Semitic morphological structure, comprising the triconsonantal root and a word pattern, plays a key role in the early orthographic processing in Arabic. Velan and Frost (2009, 2011) have previously shown using a lexical task (lexical decision) that in Hebrew, another Semitic language, TL priming effects are absent when the transposed letters are root consonants, and argued that this reflects a Semitic orthographic structure that is fundamentally different from European languages. Perea et al. (2010) replicated this finding with Arabic and extended it to the same-different task (Perea, Abu Mallouh, Garcí A-Orza, & Carreiras, 2011, Experiment 1). The authors took the latter as evidence that the Semitic morphological structure modulates prelexical orthographic processing, arguing that the masked priming same-different task is sensitive to morphology. However, Kinoshita, Norris, and Siegelman (2012) questioned this claim, noting that Perea et al. examined TL effects without taking into account allographic variations, using primes that appear with different allographs when their root letters are transposed (e.g., *عبيد - بعيد* *bʕiid-ʕbiid* ‘far-slaves’; the differing allographs are underlined in the MSA script). In contrast to Perea et al.’s (2011) finding for Arabic, Kinoshita et al. (2012), using Velan and Frost’s (2011) stimuli in Hebrew, which has much more limited position-dependent allography, found robust TL priming effects that were not modulated by morphology in the same-different task. Thus, it remains to be seen whether the finding reported by Perea et al. (2011) for Arabic is replicable when allographic variation is controlled.

The second main claim made by these authors is that allographic variation plays little or no role in visual word recognition in Arabic. This claim is based on studies (Carreiras, Perea, & Abu Mallouh, 2012, 2013) that used single letters in the same-different match task to compare identity priming effects with nonallographic, that is with no change in letter shape (e.g., *د, ڤ /d/*), and allographic (e.g., *ع, ʕ /ʕ/*) variants of the same letter. The authors reported priming effects of the same magnitude for allographic and nonallographic letter pairs, much like the finding regarding visu-

ally similar and dissimilar uppercase-lowercase letter pairs in the Roman alphabet (Kinoshita & Kaplan, 2008; Norris & Kinoshita, 2008), and concluded that “priming of abstract letter representations is a universal phenomenon” (Carreiras et al., 2012, p. 685). A limitation of this claim, however, is that allographic variation in Arabic is informative in the context of the word (a sequence of letters): the allograph *ـ* tells the reader that there is a letter preceding it and a letter following it, and that both are ligating letters. Presented as a single letter, this allograph says nothing about position within a word, and so it is not too surprising that the Arabic allographic variation functions just like the uppercase and lowercase variations in the Roman alphabet.

The recent study by Perea, Abu Mallouh, and Carreiras (2013) aimed to assess the role of visual similarity using a masked priming lexical-decision task with 3rd and 6th graders as well as adult readers. The authors substituted either a letter in a prime having the same visual form (i.e., the same allograph in terms of the ligation pattern between a word’s letters) as the target word (e.g., *كتاب - كتذب* “ktzb”–“ktaab”), or a letter having a different visual form from the target as a result of ligation (*كتاب - كتخب* *ktaab-ktxb*). The size of the priming did not differ between these two types of primes in either developing readers or adult readers. Given the parallel with the visual similarity manipulation carried out with the lowercase prime-uppercase target pairs in the Roman alphabet (e.g., *edge-EDGE* vs. *kiss-KISS*, Bowers et al., 1998), Perea et al. concluded that allographic variation plays little role in Arabic. Note however that the visual similarity manipulation concerned a nonroot letter, and that the prime and target always shared the three letters of the root {ktb}. From the point of view that lexical processing in Arabic is tuned to picking up root consonants (e.g., Boudelaa, 2014; Boudelaa & Marslen-Wilson, 2005, 2015), there is little reason to expect the two conditions to behave differently. That is, the message from this experiment may not be that visual form has no role to play, but that root priming in Arabic is robust and can be observed in both adult and developing readers.

The conclusion drawn by these authors that allography does not modulate visual word recognition processes in Arabic seems inconsistent with recent data concerning readers of MSA who have Letter Position Dyslexia (Friedmann & Haddad-Hanna, 2012). These dyslexic readers have a selective deficit in letter position encoding manifested in a disproportionate number of reading errors involving letter migrations within words. The point of interest is that their letter-migration errors are modulated by position-dependent allography. They made 85% letter migration errors with words involving no allographic variation (i.e., words comprising the same letter allograph in the base word and TL word, e.g., *تمهل - تمهل* *tmhl-thml* ‘give notice-neglect’); in contrast, words that would involve allographic variation when their letters are transposed (e.g., *جاهز - جاهز* *jaahz-jhaaz* ‘ready-device’) hardly elicited any errors. This suggests that allographic information is indeed encoded and is used to resolve uncertainty in letter position. What is unclear, however, is whether the use of letter-form information is characteristic of an immature reading system specific to individuals with dyslexia and does not apply to normal skilled readers, as suggested by Carreiras et al. (2012, p. 690).

The absence of allographic effects in Arabic as claimed by Perea et al. (2013) and Carreiras et al. (2012) is equally at variance with data from Uyghur, an agglutinative non-Semitic language from the Turkic family that uses an Arabic-based script in which both

consonants and vowels are fully specified (Yakup, Abliz, Sereno, & Perea, 2014, 2015). Using a Rapid Serial Visual Presentation (RSVP) with sentences containing jumbled words, in which the internal letters were rearranged in a way that either did or did not lead to allographic changes, Yakup et al. (2014) showed that response accuracy was significantly lower for target words in jumbled sentences involving a letter shape change, thus suggesting that position-dependent allography affects letter position coding in Uyghur. Similar results were found by the same authors using a masked priming lexical decision in which it was found that transposed and substituted letter primes that did not incur any allographic changes showed significantly more facilitation than those that did (Yakup et al., 2015).

In summary, then, the Arabic dyslexic data and the Uyghur data for which strong effects of allography have been reported are at variance with the masked priming data reported by Perea et al. (2011, 2013) and Carreiras et al. (2012), which did not find any modulatory effects of priming by allography. Given the methodological shortcomings of the Arabic masked priming studies described above, however, the role of position-dependent allography in visual word recognition in intact readers of Arabic remains to be determined.

In the present study, we addressed this issue by evaluating the extent to which allographic variation can modulate TL priming effects in Arabic. To ascertain the locus of these effects, we evaluated the effects allography has on TL priming using the masked priming lexical-decision task (Experiment 1), the same-different matching with existing Arabic words (Experiment 2), and grapho-tactically legal nonwords (Experiment 3).

### Experiment 1: Masked Priming Lexical Decision

Lexical decision is a classic lexical task in which the participant is presented with letter strings that are either real words or word-like nonwords. In this task, the subject has to verify whether each item is a word or not. This task is standardly thought to engage lexical access processes and to be sensitive to the way lexical space is organized in a given language. We elected to use this task in the first experiment because it naturally complements the same different matching task that we will use in Experiments 2 and 3. Furthermore, the lexical-decision task, but not the same-different task, requires lexical access. In the Bayesian Reader framework (Norris, 2006; Norris & Kinoshita, 2012a), in the lexical-decision task the participant has to match the input against the whole lexicon, whereas, in the same-different task, they have to match it against a single item: the referent (Norris & Kinoshita, 2008). This means that the characteristics of lexical space such as neighborhood density and morphological structure should modulate priming in lexical decision but not in the same-different match task. Accordingly, if the specific characteristics of the Arabic lexicon come into play in lexical decision, but not in the same-different match task, then we expect to see different TL priming effects in Experiment 1 compared with Experiments 2 and 3. A second reason for using lexical decision is that there has been no systematic study of orthographic priming effects in Arabic controlling for allographic variation with transposed letter primes in this task. Finally, lexical decision is a ubiquitously used task in the orthographic priming literature looking at transposed letter effects and,

as such, it will allow us to maintain comparability with previous research.

In past research using lexical decision, Velan and Frost (2009, 2011) consistently found no TL priming effects for Hebrew native words with the typical Semitic morphological structure. Perea et al. (2010) extended these results to Arabic, using transposed-letter Arabic words as primes for existing word target (e.g., معقد – معقد *mqʕd-mʕqd*, ‘seat-complex’) and found no TL priming effects; they thus concluded that “the order of the root letters is allowed only a minimum degree of perceptual noise to avoid activating the wrong root” (pp. 375, 378). The present experiment extended these studies in two respects. First, it used real word targets paired with transposed and substituted letter nonword primes comprising non-existing roots. This allowed us to establish whether the absence of TL priming effects reported by Perea et al. (2010) was attributable to competition among existing roots, or genuinely reflected the processing dynamics engaged during lexical decision in this language. Second, and more importantly, we added the manipulation of allography such that when two consonants of the base root were transposed or substituted, this either caused a change in the shape of the manipulated letter and/or brought about a redistribution of blank space locations. This variable was not controlled in the Perea et al. (2010, 2011), and as a consequence it is possible that the absence of TL effects when the root letters were manipulated in Arabic could in part be due to this confounding factor.

### Method

**Participants.** Fifty-nine participants were randomly selected from the female campus of the United Arab Emirates University to take part in this experiment. Their age ranged between 20 and 24 years old, and they all were native speakers of dialectal Emirati Arabic, used Modern Standard Arabic on a daily basis, and had normal or corrected-to-normal vision.

The sample size was guided by, and is much greater than, previous studies of TL priming lexical decision experiments in Arabic (Perea et al., 2010: 26 participants in Experiment 1, 28 participants in Experiment 2). More generally, the sample size in each of the three experiments reported here provided an estimated power greater than 0.9 to detect the effects of interest if they existed.

**Stimuli and design.** We selected 60 words to be used as targets for the ‘word’ response condition. They ranged between 4 and 8 letters in length (mean 6.12 letters), with an average frequency of 15.36 per million (range: .01–234) in the Aralex database (Boudelaa & Marslen-Wilson, 2010). Each of the words was preceded by one of six types of prime (see Table 3). The first was an Identity prime (e.g., يسعدون - يسعدون *ysʕduun-ysʕduun* ‘be happy-be happy’), and the sixth was the all-letter-different baseline nonword prime, used to establish that the task is sensitive to the masked priming manipulation (e.g., تتناجج \* *ttaaθj*). The second to fifth prime types involved the two critical manipulations, Type of Change (letter transposition vs. substitution) and Allography, crossed orthogonally. All primes were legal nonwords. In Condition 2, two letters of the TL–Allog primes were transposed without causing any allographic changes (e.g., يسعدون - يسعدون \* *ysʕduun-ysʕduun* ‘be happy’). In contrast, in Condition 3, TL+Allog, two letters of the prime were transposed so as to undergo allographic changes (e.g., يسعدون - يسعدون \* *ysʕduun-ysʕduun* ‘be happy’). Note

Table 3  
Sample Stimuli Used in Experiment 1

Stimuli	Word	Nonword
Prime		
1. Identity	يسعدون ysʕduun 'be happy'	انكهزت *ʔnkhzt
2. TL-Allog	يسعدون *ysdʕuun	انهكزت *ʔnhkzt
3. TL+Allog	يسعدون *ysdʕuun	انكزت *ʔnkzt
4. SL-Allog	يشعدون *yʃyduun	انطعزت *ʔntʕzt
5. SL+Allog	يسزون *yszruun	انكلتت *ʔnklʕt
6. Baseline	تتتتت *ttaaθj	يتخاقم *ytxaaqm
Target		
	يسعدون ysʕduun 'be happy'	انكهزت *ʔnkhzt

Note. Examples are in Arabic script with a transliteration and an English gloss where appropriate (the asterisk indicates a nonword).

for example the change of the underlined letter ʕ in the Arabic-script example from the allograph ع when flanked by two ligating letters in the base word to the allograph ع when the preceding letter does not ligate in the prime. Note further that the blank spaces appear after letters 3 and 5 in the TL+Allog prime, but after letters 4 and 5 in the target. More specifically, the allographic changes in this condition consisted of (a) changes in the shape of the letter (e.g., ع to ع or ل to ل) 48.81% of the time, (b) changes in ligation of the letters (e.g., ر to ر or خ to خ) 9.66% of the time, and (c) changes in ligation and blank space location (e.g., يَنْزِرُونَ - يَنْزِرُونَ) 41.53% of the time. In Condition 4, SL-Allog, two letters of the target were substituted to create a prime without any allographic changes. In particular, one of the substituted letters was from the same Letter group as the original letters 56.78% of the cases (e.g., \*يشعدون - يسعدون \*yʃyduun-ysʕduun 'be happy'). In the remaining 43.22% of the items, the substitution letters were from different Letter groups that nonetheless preserved the ligation pattern and blank space location of the base word (e.g., \*ينكفان - ينكفان \*ynkfqaan- yniʕlqaan 'start off'). In Condition 5, labeled SL+Allog, two letters of the target were substituted so as to cause allographic changes in the prime (e.g., \*يسزون - يسعدون \*yszruun-ysʕduun 'be happy'). These changes pertained to letter shape in 1.69% of the items, to letter ligation 33.39% of the item and to ligation and blank space relocation 64.92% of the items. Additionally, the substitution letters in this condition were from the same Letter group as the substituted letters, so that they differed only in the dots above or below them 16.95% of the time. For instance, the base word أظمها ʔtʕmhaa 'smack,' is converted into the prime أظمها ʔdʕmhaa, where one letter, the ظ, is replaced by the same Letter group ظ, while the second letter د is replaced by the different Letter group د. Despite the overall similarity between the two items, it is important to note the new blank space after the second letter of the sequence أظمها, as well as the fact that the letter ظ ligates to the right in the resulting prime while the letter ظ ligates both to the right and left in the base word. In the remaining 83.05% of cases, the substituted letters were from different Letter groups.

Beyond this, the transposed and substituted letters were always the same two root letters in the base word. In half of the stimuli the first and second letters of the root were manipulated, and in the other half the second and third or the second and fourth letters were manipulated. The manipulated letters were never the first or the last letter of the whole word. Finally, none of the roots resulting from letter transposition or letter substitution corresponded to an existing root in the language. Nine different verb word patterns were used with an average type frequency of 4913 (range: 2.4–26265) in the Aralex database.

We also created 60 grapho-tactically legal nonwords by changing one to two consonant letters of an existing Arabic word to be used as targets in the 'nonword' response condition. For example, the existing Arabic words انقهرت ʔnqhrt 'be conquered' and أسعدتنا ʔsʕdtaa 'make happy' are respectively converted into the nonwords انكهزت \*ʔnkhzt by changing two consonants and أسعظتنا \*ʔsʕdʕtaa by changing one consonant. These items ranged from 5–8 letters in length (mean: 6.13, SDEV: .57). Each of these nonwords was preceded by one of six types of primes built along the same lines as in the word response (see Table 3). The first condition was an Identity prime (e.g., انكهزت - انكهزت \*ʔnkhzt-ʔnkhzt), and the sixth was an all-letter-different baseline nonword prime (e.g., يتخاقم \*ytxaaqm). Conditions 2 to 5 constituted the critical manipulation of the experiment by orthogonally crossing Type of Change (letter transposition vs. substitution) with Allography (- Allography vs. + Allography). Specifically, Condition 2, called 'TL-Allog,' paired a base nonword target (e.g., انكهزت \*ʔnkhzt) with a prime in which two letters were transposed without causing any allographic changes (e.g., انهكزت \*ʔnhkzt). Condition 3, TL+Allog, comprised primes in which the transposition of two letters of the base nonword caused allographic changes in the resulting prime. These changes affected the letter form 45.42% of the time, letter ligation 20% of the time, and letter ligation and blank space location 34.58% of the time. In Condition 4, the SL-Allog, two letters of the target nonword were substituted without resulting in any changes either in the form of the residual letters of the base nonword, its ligation pattern or the distribution of blank spaces within it (e.g., انطعزت \*ʔntʕzt- \*ʔnkhzt). In this condition, the substituting letters were from the same Letter group as the substituted letters in 3.34% of the items. In Condition 5, SL+Allog, the two letters that were substituted in the nonword target caused allographic changes that pertained to letter form 16.61% of the time, to letter ligation in 12.71% of the cases, and to a combination of letter ligation and blank space location 70.68% of the time. The substituting and the substituted letters were from the same letter Group 4.92% of the time. The transposed and substituted letters were always the same two root letters in the base word, and none of the roots resulting from letter transposition or letter substitution exists in the language. In half of the stimuli the first and second letters of the nonexisting root were manipulated, and in the other half, the second and third letters were manipulated. Five different verb word patterns were used to form this set of stimuli, with an average type frequency of 7499 (range: 4.85–26265) in the Aralex database. Full lists of the stimuli are provided in Appendices A1 and B1.

**Procedure.** Participants were tested in groups of nine at carrel desks in a quiet room. The presentation of the stimuli and recording of response times were controlled by portable laptops using

Superlab 5. On each trial, a forward mask consisting of 22 vertical lines (|||||) in a 48-point Arabic font size was presented for 1,000 ms. For cursive Arabic scripts, this mask is preferred to the more commonly used hash mark mask used with stimuli in the Roman alphabet based on the results of several piloting tests, and has been used in previous masked priming studies with Arabic (Boudelaa & Marslen-Wilson, 2004, 2005, 2011, 2015). Next, a prime in 24-point Arabic font was presented for 50 ms, and was then replaced by a target word or nonword in 36 Arabic font size. The target remained on the screen either until the participant's response or for 2,000 ms, whichever occurred first. Participants were instructed that they would see strings of Arabic letters and that their task was to press the button marked نعم "YES" with their right index finger if the target was a word, and the button marked لا "NO" with their left index finger if the target was a nonword. Participants were instructed to make this decision as rapidly and as accurately as possible. When debriefed at the end of the experiment, none of the subjects reported conscious knowledge of the priming items. Each participant received a different order of trials. The experiment began with 32 practice trials with properties similar to those of the experimental trials followed by the experimental trials. The whole session lasted approximately 10 minutes.

## Results

In this experiment, as well as the next two, the preliminary treatment of the data was as follows: Incorrect responses and response times less than 200 ms or greater than 1800 ms were removed. For the *word response* data, this procedure resulted in the removal of 1.49% of all the data (.98% errors and .50% outliers). For the *nonword response* data, 5.47% of the total data were excluded (2.65% errors and 2.82% outliers). The full raw data set for this experiment and the next two is accessible here: <https://osf.io/pmvxk/?show=revision>. Mean RTs and error rates for *word* and *nonword* trials are shown in Table 4.

**Word responses.** We analyzed the four critical conditions (i.e., TL-Allog; SL-Allog, TL+Allog, and SL+Allog) using a linear mixed effects modeling approach. We first examined the shape of reaction time (RT) distribution for correct trials requiring the WORD response (a total of 2360 observations for the four conditions under consideration). All RTs were log transformed to best approximate a normal distribution, and to meet the assumption

of the linear mixed effects model. The data were then submitted to a linear mixed-effects model using the lme4 package implemented in R 3.2.3 (Bates, Maechler, Bolker, & Walker, 2013). The model included as fixed factors the RTs on the previous trial (PrevRT), along with a full factorial combination of Type of Change (i.e., *Transposed vs. Substituted*), Allography (i.e., *plus allography vs. minus allography*; both of which were deviation-contrast coded), and random intercepts and random slopes for *subjects*, *prime words* and *target words*. All models used for RT latencies and error count measures contained the full random structure as recommended by Barr, Levy, Scheepers, and Tily (2013). If a model containing the full random structure failed to converge, it was systematically pruned by removing interactions between random effects until the model converged. Thus all results reported here are based on successfully converging models.

After removing the RTs of error trials from both the current and previous trials, there were 2325 data points. The degrees of freedom and the *p* values in this experiment and the next two were estimated using Satterthwaite's approximation as implemented in the lmerTest package (Kuznetsova, Brockhoff, & Christensen, 2013). Neither the main effect of Type of Change,  $F(1, 113.69) = 3.570$ ,  $p = .06$ , nor that of Allography,  $F(1, 48.62) = .288$ ,  $p = .59$ , or their interaction was significant,  $F(1, 154.47) = .085$ ,  $p = .77$ . The only significant effect in this model was that of PrevRT,  $F(1, 2245.76) = 17.61$ ,  $p < .001$ . We also conducted pairwise post hoc comparisons systematically contrasting TL-Allog with TL+Allog and SL-Allog, as well as the SL+Allog with the SL-Allog and the TL+Allog using Bonferroni-Holm protection levels. The results of these comparisons indicated that performance in the TL-Allog condition did not significantly differ from performance in TL+Allog ( $p = 1.0$ ), SL-Allog ( $p = 1.0$ ), or indeed SL+Allog ( $p = .6$ ). Similarly, the TL+Allog condition did not differ significantly either from the SL-Allog ( $p = .1$ ) or AL+Allog ( $p = 1.0$ ), and finally, the two SL conditions were not significantly different from each other ( $p = 1.0$ ). As a paradigm check, we assessed priming in the Identity condition against the unrelated baseline, the two TL conditions, and the two SL conditions. In each of these comparisons, the identity condition showed significant facilitation (all  $ps < .01$ ), suggesting that the absence of facilitation in our four conditions of interest was not due to lack of statistical power, but was a genuine outcome resulting from the processing dynamics engaged by the primed lexical-decision task in Arabic.

In a second series of analyses, we also evaluated the potential effects of two variables on priming. The first was Form of Allography, which focused on the TL+Allog and the SL+Allog contrast and aimed at assessing the extent to which the three forms of allography (i.e., change in letter form, change in ligation, and change in blank space location within the word) can affect priming. The second, called Letter Group, focused on the SL-Allog and the SL+Allog conditions and sought to determine if priming was modulated by whether the letters substituting each other belonged to the same letter group. Accordingly, we coded the data into four categories on the basis of whether they comprised (a) two substituted letters belonging to the same group and occurring in the same position across prime and target, (b) two substituted letters belonging to the same group, but occurring in different positions, (c) one substituted letter belonging to the same group, and occurring in the same position, and (d) one substituted letter belonging

Table 4  
Mean Lexical Decision Response Latencies (RT, in ms), Percent Error Rates (in Parentheses), and Magnitude of Facilitation (Priming in ms) in Experiment 1 (Lexical Decision Task)

Response and prime type	Word	Nonword
Identity	598 (.68)	737 (2.37)
TL-Allog	657 (.51)	763 (2.03)
SL-Allog	666 (1.53)	750 (3.39)
TL priming effect: SL-Allog minus TL-Allog	9	-13
TL+Allog	663 (1.01)	756 (2.88)
SL+Allog	678 (1.01)	750 (3.22)
Baseline	684 (1.19)	816 (2.03)
TL priming effect SL+Allog minus TL+Allog	15	-6

to the same group, but occurring in different positions across prime and target.

The first model revealed no significant effects either for Type of Change,  $F(1, 795.82) = 1.6166, p = .203$ , Form of Allography,  $F(2, 41.30) = 1.7723, p = .17$ , or their interaction,  $F(2, 795.40) = .0354, p = .97$ . The only significant effect in this model was that of the control variable PrevRT,  $F(1, 1108.55) = 18.115, p < .001$ . Similarly, the second model suggested that neither the effects of Allography,  $F(1, 51.36) = .107, p = .74$ , nor those of Letter Group,  $F(3, 82.07) = 1.4374, p = .24$ , or indeed the interaction between them was significant,  $F(2, 95.20) = 1.132, p = .33$ . PrevRT was however, highly significant,  $F(1, 1086.94) = 19.047, p < .001$ .

The error data were analyzed using a logit mixed model (Jaeger, 2008) with the same fixed and random factors as used in the RT models except for PrevRT. The results did not reveal any significant changes in the log odds of the response variable as a function of the predictor Type of Change ( $t = .267, p = .79$ ), Allography ( $t = .383, p = .70$ ), or their interaction ( $t = .185, p = .85$ ). We also ran two further mixed effects models focusing on the possible modulatory effects of Form of Allography in the TL+Allog and the SL+Allog conditions and on those of Letter Group within the two substituted letter conditions. The first model revealed no significant effects for Type of Change ( $t = .285, p = .78$ ), Form of Allography ( $t = .292, p = .77$ ), or the interaction between them ( $t = -.282, p = .77$ ), and neither did the second model, revealing unreliable effects for Allography ( $t = .440, p = .66$ ), Letter Group ( $t = -.107, p = .92$ ) and their interaction ( $t = .131, p = .90$ ).

Given the absence of a significant NHST effect of TL priming in this experiment, we decided to investigate the effect further using Bayes Factors. Not only does a Bayes factor analysis allow us to quantify the relative evidence both for and against the hypothesis that there is an effect of TL, but it also addresses the possibility that the absence of a significant TL effect in NHST might be a consequence of lack of power. If a Bayes Factor analysis gives strong support for the absence of TL priming, this cannot be a result of lack of power. We calculated the Bayes factor using the Bayes factor package (Version 9.12–2, Rouder & Morey, 2013) available in R to compare two mixed effects models that differed in the inclusion of the variable Type of Change, which contrasted letter transposition with letter substitution. Model 1 was the mixed effects model described above, and Model 2 did not include Type of Change. We then used the “compare function” with the default JZS prior to compute the Bayes Factor using Model 1 as the denominator. Our Bayes factor ( $BF_{01}$ ) was  $73 \pm 4\%$ , thus providing very strong evidence for the null hypothesis that there is no TL priming effect in lexical decision in Arabic.

**Nonword responses.** The nonword RT data, which consisted of 2290 data points after removal of false alarms and outliers, were submitted to the same analyses as the word data, first with Type of Change and Allography as fixed factors, and random intercepts and slopes for *subjects*, *prime words* and *target words*. No significant effects were found for Type of Change,  $F(1, 8.93) = .077, p = .78$ , Allography,  $F(1, 97.37) = .415, p = .52$ , or indeed their two-way interaction,  $F(1, 221.12) = .049, p = .82$ . We did not explore the effects of Form of Allography or Letter Group with the nonword data because the effects of letter transposition and letter substitution were numerically in the wrong direction with the

pooled TL conditions averaging 759 ms against a pooled average of 750 ms in the SL conditions.

Turning to the error data for the nonwords, a logit mixed model (Jaeger, 2008) with the same fixed and random factors as used with the word error data revealed no significant effects of Type of Change ( $t = .116, p = .91$ ), Allography ( $t = .508, p = .61$ ), or their interaction ( $t = 1.930, p = .05$ ). A second model focusing only on the two allographic conditions (i.e., TL+Allog and SL+Allog) revealed the effects of Type of Change ( $t = .306, p = .76$ ), Type of Allography ( $t = .408, p = .68$ ) and their interaction ( $t = -.558, p = .58$ ) to be nonsignificant. Another model focused on the two substitution letter conditions (i.e., SL–Allog and SL+Allog) and yielded no effects of Allography ( $t = -.960, p = .34$ ), Letter Group ( $t = -.138, p = .89$ ), or their interaction ( $t = .146, p = .88$ ).

Finally, we sought to quantify the amount of evidence for the presence of orthographic effects in lexical decision by comparing two logit models that differed in the inclusion of the variable Type of Change (i.e., letter transposition vs. letter substitution). Using the “compare function” with the default JZS prior to compute the Bayes factor with the model including Type of Change as the denominator, revealed the Bayes factor ( $BF_{10}$ ) to be  $299 \pm 7\%$ , suggesting that there was very little evidence for the effects of the variable Type of Change. This corroborates the idea that TL priming is highly unlikely to obtain in lexical decision in Arabic.

## Discussion

This experiment used masked lexical decision priming to determine whether TL priming effects can be observed in Arabic and, if they do, whether they are modulated by allographic variation. The results clearly show that TL priming effects do not obtain in this language. This outcome replicates the pattern observed consistently with Hebrew, another Semitic language with the Semitic morphology based on consonantal roots (Velan & Frost, 2009, 2011) and extends the results originally reported by Perea et al. (2010) for Arabic word primes to nonword primes. Furthermore, our post hoc analyses suggest that the different types of allography (i.e., change in letter form, letter ligation, or blank space location) behave in the same way, consistent with previous reports in the literature (Perea, Abu Mallouh, Mohammed, Khalifa, & Carreiras, 2016). Similarly, the fact that priming was not modulated by whether or not the manipulated letters came from the same Letter Group suggests that, at least in lexical decision, individual letters and allographs are treated as wholes and not analyzed into a letter shape of some sort plus a number of superposed dots. We do acknowledge though that these two outcomes are based on post hoc analyses of a subset of the data and should, therefore, be taken with due caution.

More generally, our results can be accommodated within the *noisy position* Bayesian Reader (Norris & Kinoshita, 2012a) as follows. According to this view, word recognition consists of accumulating evidence from the visual input via noisy perceptual sampling. Within this framework a *yes* response in the lexical-decision task is made when there is enough evidence to decide that the input is more likely to be a word than a nonword, whereas a *no* response is made when there is enough evidence to determine that the input is unlikely to have been generated by a word (Norris, 2006; Norris & Kinoshita, 2008). Because lexical decision is



standardly thought to trigger lexical processes, this view implies that the amount of evidence needed to make a decision will be modulated by the structural and distributional characteristics of the lexical space. In the present case, we independently know that the lexical status of a string of letters in Arabic is primarily determined by whether its root exists or not (Boudelaa, 2014; Boudelaa & Marslen-Wilson, 2015). We also know that the lexical space in which roots are organized is densely populated such that transposing two letters in any of the commonly used 4858 Arabic trilateral and quadrilateral roots results in an existing root 54% of the time.<sup>4</sup> As an example, consider the Arabic root (e.g., {rtb} *tidying up*), which consists of three consonants arranged in a specific order. If the order is changed, completely different roots are obtained (e.g., {rbt} *patting*, {trb} *sand*, {tbr} *gold*, {brt} *ax*, {btr} *cutting off*), suggesting that the lexical space in Arabic is dense compared with that of a language like English where the rearrangement of letters within a word (e.g., *right*, *can*, *moot*) typically yields nonexisting word (e.g., *rihgt*, *nac*, *toom*).

It is well established in the masked priming literature with European languages written in the Roman alphabet that the “neighborhood density constraint” operates: Specifically, in lexical decision, orthographic priming effects by (substituted-letter/SL) non-word neighbor primes (e.g., *bamp-CAMP*; *bontrast-CONTRAST*) are weak or absent when the prime and target are drawn from high-density neighborhoods (Forster, Davis, Schoknecht, & Carter, 1987). In Semitic languages like Arabic, the lexical space is structured around the triconsonantal root, and it is densely populated by TL (as well as SL) neighbor roots. In lexical decision then, TL priming effects are difficult to observe in Semitic languages, as has been shown repeatedly by Frost and colleagues (e.g., Velan & Frost, 2009, 2011) in Hebrew, and in Arabic by Perea et al. (2010), and in the present experiment. In this view, the cross-language contrast in the finding of TL priming effects in lexical decision is due to the density of lexical space, and the structure of the orthographic representations that comprise the lexical space. In English and other European languages written in the Roman alphabet the orthographic representations that constitute the lexical space are a linear sequence of abstract letter identities. This lexical space is sparsely populated by TL neighbors. In contrast, the Semitic morphological structure is nonlinear, with the word pattern interleaved with the triconsonantal root. The lexical space is organized around the triconsonantal root, and is densely populated with TL neighbors.

A further implication of the *Bayesian Reader* view of masked priming is that if we were to use a task that does not engage the lexical access process, such as the same–different match, the otherwise pervasive effects of the Semitic morphological structure should have little impact. As noted, in this task, the input is not matched against the whole lexicon, but only against the single referent item. Because the priming effects should now reflect the matching process against the prelexical orthographic representation consisting of abstract letter identities we should see the emergence of TL-priming which should then be modulated by allographic variation. This is the goal of Experiment 2.

## Experiment 2

This experiment used the same–different match task to test whether the TL priming effect is modulated by allographic varia-

tion in Arabic words. In this task, participants are first presented with a referent and are asked to decide whether a subsequently presented target is the same as or different from, the referent. The masked priming procedure is otherwise identical to that used in the lexical-decision task with a forward mask consisting, in this case, of 22 vertical lines, followed a briefly presented prime that is in turn backward-masked by the target so that participants are unaware of the identity of the prime. According to the *noisy channel Bayesian Reader* view (Norris, 2006; Norris & Kinoshita, 2012a), TL priming effects in this task arise because in the brief time the prime is available for processing, the spatial position of adjacent letters, and hence their relative order, is uncertain. As noted, allographic variation in Arabic is position-dependent, with some letters changing shape depending on their position within a word. Friedmann and Haddad-Hanna’s (2012) findings suggest that Arabic readers suffering from Letter Position Dyslexia use allographic variation as a cue to reduce the uncertainty in letter position, as the letter form can provide a cue regarding the letter’s position. A prediction that follows from this is that allographic variation would modulate the TL priming effect such that the effect would be reduced when allographic letters are transposed compared with when nonallographic letters are transposed. In addition, our letter transposition manipulation always involved root letters. Hence the experiment also served as a replication of Perea et al. (2011, Experiment 1), testing their claim that the same–different task is sensitive to morphology and hence TL priming effect would be absent when the transposition involves root letters.

## Method

**Participants.** Sixty-seven female volunteer students from the United Arab Emirates University participated in the experiment. They were aged 20–24 and were native speakers of dialectal Emirati Arabic. They all used Modern Standard Arabic on a daily basis, and had normal or corrected-to-normal vision. The sample size was guided by, and is much greater than, previous studies of TL priming same–different experiments in Arabic (Perea et al., 2011, 20 participants).

**Stimuli and design.** The stimuli and design for the *same* response trials were identical to those used in Experiment 1 for the *yes*-response except for the use of the target items as a reference for the *same* response condition. Table 5 displays sample stimuli used in this experiment.

For the *different* response condition, we matched another 60 words to those used in the same response condition and used them as targets. These targets ranged in length between five and eight letters (mean 6.35 letters), with an average frequency of 16.86 (range: .03–237.42). They were based on six different verb word patterns with an average frequency of 4193 (range: 2.41–26265). The construction of the transposed and substituted letter with and

<sup>4</sup> We compared this with the case in English by transposing the letters of 592 three-letter English words from the Celex database (Baayen, Piepenbrock, & Gulikers, 1995). Each base word gave rise to five possible permutations with a total of 2900 unique permutations (excluding repeats from items like *mum* and *pip*). Of these 2900 items, only 193 corresponded to existing words (e.g., *cat-act*; *apt-tap*). This means that letter transposition in English results in an existing word only 6.65% of the time, suggesting a lightly populated lexical space.

Table 5  
Sample Stimuli Used in Experiment 2

Stimuli	Same	Different
Reference	يسعدون ysʕduun 'be happy'	يخلدون yxlɗuun 'be eternal'
Prime		
1. Identity	يسعدون ysʕduun 'be happy'	يخلدون yxlɗuun 'be eternal'
2. TL–Allog	يسعدون *ysɗʕuun	يخلدون *yxlɗuun
3. TL+Allog	يسعدون *ysɗʕuun	يخلدون *yxlɗuun
4. SL–Allog	يشعدون *yʃɗʕuun	يظنون *yɗʕbɗuun
5. SL+Allog	يسزرون *yszruun	يخنكون *yxɗkuun
6. Baseline	تتناجح *ttnaaθj	نلشدهم *nlʃdhm
Target	يسعدون ysʕduun 'be happy'	ينتفعون yntfʕuun 'benefit'

Note. Examples are in Arabic script with a transliteration and an English gloss where appropriate (the asterisk indicates a nonword).

without allography conditions as well as the construction of the unrelated and identity primes was identical to that of the trials in the *same* response condition. For the TL+Allog condition, the allographic changes consisted of letter form changes in 42.54% of the items, of ligation changes in changes 22.24% of the time, and of a combination of ligation changes and blank space relocation in 35.22% of the items. For SL+Allog, 10.75% of the changes were letter form changes, and another 10.75% were ligation changes, while the remaining 78.51% were a combination of ligation changes and blank space relocation. Additionally, the substituting and the substituted letters were from the same letter Group 9.40% of the time, whereas for the SL–Allog condition the manipulated letters came from the same letter Group 21.34% of the time. The *different* response reference items consisted of a further 60 words with an average length of 6.25 letters (range: 4–8) and an average frequency of 22.18 (range: .03–244.73). To maximize the difference between the reference words and their associated targets, the references were built using as many verb word patterns as possible—more specifically, using 12 of the 15 patterns existing in the language. Their average frequency was 4592 (range: 2.14–26265). A series of paired *t* tests revealed no differences between the experimental items in the various conditions in terms of their distributional characteristics (all *ps* > .5).

Six experimental lists were constructed so that each target appeared once in each set, but each time in a different priming condition. Different groups of participants were randomly assigned to each list. The full list of stimuli is in [Appendixes A1](#) and [A2](#).

**Procedure.** The general procedure was identical to that in Experiment 1 with the exception that each trial began with the presentation of a reference stimulus in 36-point Arabic font above a forward mask consisting of 22 vertical lines (|||||) in a 48-point Arabic font size for 1,000 ms. Next, the reference disappeared, and the forward mask was replaced by a prime in 24-point

Times New Roman Arabic font presented for 50 ms. Then, the prime was replaced by the target word in 36 Times New Roman Arabic font size. The target remained on the screen either until the participant's response or for 2,000 ms, whichever occurred sooner. Participants were instructed that they would see strings of Arabic letters and that their task was to press the button marked نعم "YES" with their right index finger if the reference and target were the same, and the button marked لا "NO" with their left index finger if the reference and target were different. Participants were instructed to make this decision as rapidly and as accurately as possible. When debriefed at the end of the experiment, none of the subjects reported conscious knowledge of the priming items. Each participant received a different order of trials. The experiment began with 32 practice trials with properties similar to those of experimental trials followed by experimental trials. The whole session lasted approximately 12 min.

## Results

The analysis of RTs and errors followed the same procedure as Experiment 1 and revealed an overall error rate of 5.17% for the *same response* data (5.14% errors and .024% outliers). For the *different response* data, 4.70% of the overall data were excluded (4.67% errors and .024% outliers). Mean RTs and error rates for the *Same* and *Different* trials are shown in [Table 6](#).

**Same responses.** As in the previous experiment, we analyzed the four critical conditions (i.e., TL–Allog; SL–Allog, TL+Allog, and SL+Allog) using a linear mixed effects modeling approach. We examined the shape of the RT distribution of the correct trials requiring the SAME response (a total of 2680 observations for the four conditions under consideration), and log-transformed them to best approximate a normal distribution, and to meet the assumption of the linear mixed effects model. We then fitted the full random structure linear mixed effects model with RTs on the previous trial (PrevRT) as fixed factors and a full factorial combination of Type of Change (i.e., *Transposed vs. Substituted*), and Allography (i.e., *plus allography vs. minus allography*; both of which were deviation-contrast coded) and random intercepts and slopes for *subjects*, *prime words* and *target*

Table 6  
Mean Response Latencies (RT, in ms), Percent Error Rates (in Parentheses), and Magnitude of Facilitation (Priming in ms) in Experiment 2 (Same–Different Task With Words)

Response and prime type	Same	Different
1. Identity	494 (5.07)	618 (5.67)
2. TL–Allog	486 (4.78)	613 (4.93)
3. SL–Allog	545 (4.63)	620 (4.48)
TL priming effect: SL–Allog minus TL–Allog	59	8
4. TL+Allog	517 (3.28)	614 (5.67)
5. SL+Allog	556 (3.43)	606 (4.33)
6. Baseline	570 (9.70)	627 (3.13)
TL priming effect SL+Allog minus TL+Allog	39	–8

Note. TL–Allog = Transposed Letter prime without allography; TL+Allog = Transposed Letter prime plus allography; SL–Allog = Substituted Letter prime without allography; SL+Allog = Substituted Letter prime plus allography.

words. If the full random structure model failed to converge, we trimmed it until it did. After removing RTs on error trials from both the current and previous trials, there were 2573 data points, with 67 subjects and 40 targets.

The main effect of Type of Change was significant,  $F(1, 76.11) = 59.008, p < .001$ , indicating a significant TL priming effect overall. Similarly, the main effect of Allography was also significant,  $F(1, 172.87) = 13.607, p < .001$ , as was that of PrevRT,  $F(1, 2501.68) = 46.526, p < .001$ . More importantly, the interaction between Type of Change and Allography was also significant,  $F(1, 173.95) = 4.260, p < .04$ , as indicated by the reduced TL priming effects in the +Allography condition shown in Table 6. Pairwise comparisons using Bonferroni-Holm tests yielded a statistically reliable difference between TL-Allog and SL-Allog ( $p < .001$ ) and the TL+Allog and SL-Allog ( $p < .001$ ).

We then ran two models. The first focused on the TL+Allog and the SL+Allog conditions to assess whether Form of Allography (i.e., letter shape change, ligation change and blank location change) modulated response times differently. The results revealed that Type of Change (i.e., letter transposition vs. letter substitution) had a significant effect,  $F(1, 56.50) = 25.159, p < .001$ , whereas Form of Allography,  $F(2, 53.07) = .994, p < .38$ , and the two-way interaction Type of Change by Form of Allography,  $F(2, 68.64) = .739, p = .48$ , did not. The control variable PrevRT had a significant effect,  $F(1, 1243.62) = 47.126, p < .001$ . The second model focused on the two SL conditions with a view to determining whether response latencies were differentially modulated by Letter Group, that is by whether the substituted letters belonged to the same letter group or not. The results indicated that while the effects of Allography,  $F(1, 5.55) = 1.231, p = .27$ , and the interaction between Allography and Letter Group,  $F(2, 111.04) = 1.277, p = .28$ , were not significant, those of Letter Group,  $F(3, 69.98) = 4.493, p < .006$ , and PrevRT,  $F(1, 1231.99) = 42.969, p < .001$ , were reliable.

Turning to the errors in the same response data, we used a logit mixed model approach as in Experiment 1, with the same fixed and random factors as used in the RT model except for PrevRT. This analysis revealed no significant effects of Type of Change ( $t = -1.475, p = .14$ ), Allography ( $t = -.415, p = .69$ ), or the interaction between them ( $t = 1.238, p = .22$ ). We also carried out two sets of analyses with the same structure as above except that the first focused solely on the TL+Allog and the SL+Allog conditions, and included only Type of Change and Form of Allography as fixed factors, while the second focused on the two SL conditions and included only Allography and Letter Group as fixed factors. For the first model, the results showed that neither Type of Change ( $t = .417, p = .68$ ), Form of Allography ( $t = -.123, p = .90$ ), nor the interaction between them ( $t = 0.248, p = .80$ ) was reliable. Analogously, the second model also revealed no significant effects for Allography ( $t = -1.283, p = .20$ ), Letter Group ( $t = -1.182, p = .28$ ), or their two-way interaction ( $t = 1.448, p = .15$ ).

Finally, we computed the Bayes factor to quantify the amount of evidence for the two-way interaction Type of Change  $\times$  Allography by comparing two mixed-effects models that differed in the inclusion of this interaction term. Model 1 was the mixed effects model described above, while Model 2 did not include the two-way interaction. We then used the “compare” function with the

default JZS prior to calculate the Bayes factor with Model 2 as the denominator. The Bayes factor was  $21 \pm 5.24\%$ , suggesting very strong evidence for the interaction—that is for the hypothesis that the magnitude of priming was modulated differently by allography.

**Different responses.** The same statistical analyses as above were applied to the Different trials, and consistent with the literature (Norris & Kinoshita, 2008), revealed no effects either for Type of Change,  $F(1, 173.77) = .056, p = .81$ , Allography,  $F(1, 178.39) = 2.073, p = .15$ , or their interaction,  $F(1, 18.17) = .330, p = .57$ . The analysis of the potential effects of Form of Allography in the context of the TL+Allog and the SL+Allog conditions revealed no significant effects for Type of Change,  $F(1, 59.76) = 0.211, p < .65$ , Form of Allography,  $F(2, 78.96) = 1.473, p = .24$ , or the interaction between them,  $F(2, 107.75) = 2.257, p = .11$ . The only significant effect was that of the control variable PrevRT,  $F(1, 1218.12) = 40.809, p < .001$ . Similarly the analysis focusing on the two substituted letter conditions revealed no significant effects for Allography,  $F(1, 56.34) = 1.7814, p = .19$ , Letter Group,  $F(2, 115.40) = 0.3204, p = .726$ , or their interaction,  $F(2, 120.58) = 2.5943, p = .08$ ; only the effects of PrevRT were significant,  $F(1, 1263.89) = 20.7096, p < .001$ .

The error responses to Different trials were also submitted to the same logit model as those of the Same responses. The effects of Type of Change ( $t = -1.475, p = .14$ ), Allography ( $t = -.415, p = .69$ ), and their interaction ( $t = 1.238, p = .22$ ) were not significant. Further post hoc analyses of the two allography conditions (i.e., TL+Allog and SL+Allog) yielded no significant effects of Type of Change ( $t = -0.341, p = .74$ ), Form of Allography ( $t = -1.192, p = .23$ ), or their interaction ( $t = 1.285, p = .20$ ). Similar analyses of the two SL conditions indicated that the effects of Allography ( $t = -1.161, p = .25$ ), Letter Group ( $t = -1.544, p = .12$ ) and their interaction ( $t = 1.257, p = .21$ ) were not significant.

## Discussion

The results of this experiment are clear: In Arabic, the same-different matching task reveals a robust TL priming effect that is modulated by allographic variation. This finding contrasts with the extant literature on Arabic word recognition in two respects. First, the finding of TL priming effect in the same-different task when the transposed letters are root letters is at odds with the absence of such an effect reported by Perea et al. (2011). The present finding, however, replicates the effects reported by Kinoshita et al. (2012) for Hebrew, another Semitic language, but with a much more limited position-dependent allography. Surprisingly our results also suggest that the different forms of allography (i.e., form change, ligation change, and blank space location) do not exert differential modulatory effects on priming. There was no significant interaction between Type of Change and Form of Allography for either the latency or error data, and there was an absence of an effect for Form of Allography. However, this finding needs to be interpreted with caution because it is based on post hoc analyses with unmatched numbers of observations. For instance, 42.5% of the allographic changes pertained to changes in Letter Form in the TL+Allog condition but only 1.69% were Letter Form changes in the SL+Allog condition. With respect to the effects of Letter Group, our post hoc analyses suggest however that this variable

can modulate the effects of letter substitution, with letters substituted from the same letter group yielding more priming than those substituted from a different group. Although this outcome makes intuitive sense, it has to be interpreted cautiously for a number of reasons. First, our experiment was not specifically designed to evaluate the effects of Letter Group. Second, the effects of this variable were not significant in either Experiment 1 or Experiment 2. Finally, these effects are inconsistent with a recent report by Perea et al. (2016), who showed that priming effects in Arabic did not vary as function of Letter group membership: A target like صحفية *s<sup>h</sup>fyt* ‘journalist’ has comparable latencies when preceded by an SL prime from the same Letter group (e.g., صحفية\* *s<sup>h</sup>fyt*) or a different Letter group (e.g., مكفية\* *s<sup>h</sup>kfyt*), suggesting that information about the dots is rapidly uptaken by the lexical processing system. The foregoing discussion illustrates the elusive nature of letter group effects and calls for further work to elucidate the true role of this variable.

The TL priming effect in the same–different task is interpreted as having its origin in the noisy perception of letter order, and is not assumed to be a consequence of the structure of the language (cf. Gómez et al., 2008; Kinoshita & Norris, 2009). In the same–different task, which does not require lexical access, TL priming effects are unaffected by morphological structure (Kinoshita et al., 2012). This contrasts with tasks such as lexical decision where morphological structure does influence processing at an early stage, and where integration of evidence about roots and word patterns is crucial to making the decision. This is well documented in the work of Boudelaa and Marslen-Wilson (2005), who reported strong root priming effects at an SOA of 32 ms in Arabic, and the work of Friedmann and Gvion (2001), who described two Hebrew patients with peripheral dyslexia whose migration errors were significantly modulated by the morphological structure of the word. Our point here is that word recognition is a dynamic process during which evidence is accumulated to implement a task-driven decision. In the same–different match task, the decision concerns whether the target item matches a single reference item. Masked priming in this task is insensitive to the morphological structure (Duñabeitia et al., 2011), and (in the brief period of time that the prime is available) the prime is coded as a linear sequence of abstract letter identities. In contrast, in lexical decision, the decision is heavily based on whether the target item matches (any) item(s) in the lexicon, which, in Semitic languages, is organized in terms of nonconcatenative roots + word patterns. Thus during this task, the linguistic processor has to constantly gather evidence about roots and word patterns, and evaluate (a) whether these two components exist in the lexicon, and (b) whether their combination is licensed—that is, a real word and not a morphologically structured pseudoword. It is the ubiquitous morphological structure that characterizes Arabic words and the TL and SL nonwords as used here that determines the organization of the lexicon, triggers morphemic parsing in any task requiring lexical access, and ultimately imposes higher decision criteria during lexical decision.

The present finding of robust TL priming effects in Arabic with the letter transposition manipulation involving the root letters reinforces this interpretation. It argues against Perea et al.’s (2011) interpretation that Semitic morphology modulates TL priming effects in the same–different task. Given the many differences between our study and Perea et al.’s, particularly their failure to control important properties of the stimuli including the position-

dependent allography, it is hard to pinpoint why TL priming was absent in their study. One plausible explanation for this discrepancy between the two studies however is that we used more than twice the number of participants they did, and it may well be that their study lacked the necessary power to detect significant TL priming.

Second, and more importantly, this is the first demonstration that allographic variation modulates masked priming effects. On the surface, this finding seems to contrast sharply with those reported by Carreiras, Perea, and Abu Mallouh described earlier. On a closer look, however, there is no real discrepancy between our results and theirs. Recall that Carreiras et al. (2012, 2013) used single letters and found that the visual similarity of allographs did not modulate the size of identity priming effects. Presented as a single letter, allographic variation in Arabic has nothing to say about letter position and hence it is not surprising that the visual similarity manipulation functioned just like the visual similarity of the allographs in the Roman alphabet (e.g., *a/A* vs. *c/C*) reported by Kinoshita and Kaplan (2008). In a different study using the lexical-decision task, Perea et al. (2013) did use word stimuli and manipulated the visual similarity of allographs substituted in the prime, and still found that it did not modulate the size of priming. As also noted, however, the critical allograph similarity manipulation concerned nonroot letters and the task used by Perea et al. was lexical decision, so the absence of the allograph similarity effect can be explained in terms of the view that lexical processing in Arabic is tuned to pick up root consonants (Boudelaa & Marslen-Wilson, 2005, 2013, 2015).

### Experiment 3

Experiment 2 used stimuli that consisted of words as referents and targets to show that TL-priming effects were modulated by allographic changes caused by letter transposition. Experiment 3 strengthens this case by showing that priming in the same–different matching task obtains even with nonword stimuli thus reinforcing the claim that the position-dependent allography impacts prelexical orthographic representations.

### Method

**Participants.** Sixty-two female volunteer students from the same population as in Experiments 1 and 2 took part in this experiment. They were 20 to 24 years of age and were native speakers of dialectal Emirati Arabic who used Modern Standard Arabic on a daily basis, and had normal or corrected-to-normal vision. The choice of this sample size was informed by common practice in the field.

**Stimuli and design.** A 60 nonword set was used in the *same response*. It was built by changing one to two consonant letters in an existing word to create an ortho-tactically legal nonword ranging between five and eight letters in length (mean: 6.13). They were formed using five different word patterns with an average frequency of 7499.86 (range: 4.85–26265). The construction of the transposed and substituted letter with and without allography conditions as well as the construction of the unrelated and identity primes was identical to that of the trials in the *same response* condition of Experiment 2. For the TL+Allog condition, the allographic changes were letter form changes 55.32% of the time

and ligation and blank space location changes 44.68% of the time. For the SL+Allog condition these changes were letter form changes 1.96% of the time and Ligation and blank space location changes 98.39% of the time. Additionally, the substituted letters in this condition did not belong to the same letter group. The same holds for the SL–Allog, where none of the substituted letters came from the same letter group.

The *different response* set consisted of another 60 nonwords also built by changing one to two consonants of an existing word to form a legal orthographic string. They ranged in length between 5 and 8 letters (mean 6.25 letters). These items were based on five different verb word patterns with an average frequency of 6652 (range: 4.85–26265). The construction of the transposed and substituted letter with and without allography condition as well as the construction of the unrelated and identity primes was identical to that of the trials in the *same response* condition. The *different referents* were made up of a further 60 nonwords with an average length of 6.22 letters (range: 5–8), also built by changing one or two letters of an existing word. Seven different verb word patterns were used with these items with an average frequency of 1573 (range: 4.85–26265). Where the form of allography is concerned, the changes in the TL+Allog condition consisted of letter form changes 50.16% of the time and ligation and blank space relocation 49.84% of the time. In the SL+Allog, the changes were letter form changes 1.61% of the time, ligation changes 82.58% of the time, and ligation and blank space relocation 15.81% of the time. Further, in this condition, the proportion of the substituted letters belonging to the same letter group was 1.61%, whereas for the SL–Allog, this proportion was 21.61%. Six experimental lists were constructed so that each target appeared once in each set, but each time in a different priming condition as illustrated in Table 7. Different groups of participants were randomly assigned to each list.

**Procedure.** This was identical to Experiment 2.

## Results

Applying the same pruning procedure as in the previous two experiments resulted in the exclusion of 7.15% of the data points

Table 7  
Experiment 3 Sample Nonword Stimuli in Arabic Script and Transliteration

Stimuli	Same	Different
Reference	انكهزت *ʔnkhzt	تجغدون *tjyduun
Prime		
1. Identity	انكهزت *ʔnkhzt	تجغدون *tjyduun
2. TL–Allog	انهكزت *ʔnhkzt	تجغدون *tjyduun
3. TL+Allog	انكز هت *ʔnkzht	تجدعون *tjdʔuun
4. SL–Allog	انطعزت *ʔntʔzt	تظفدون *tʔfduun
5. SL+Allog	انكاطت *ʔnklʔt	تجنلون *tjnlun
6. Baseline	يتخاقم *ytxaaqm	العهكا *ʔʔkhaa
Target	انكهزت *ʔnkhzt	انفشكن *ʔnfʃkn

(7.07% errors and .08% outliers) from the *same response* data, and 5.99% for the *different response* data (5.91% errors and .08% outliers). This left 2331 data observations in the four conditions of interest. We fitted the full random structure model with Type of Change (TL vs. SL), Allography (+Allog vs. –Allog), their interaction, previous trial RT (PrevRT) as fixed factors, and Subjects, Primes, and Targets, as random factors each with a random intercept and random slope. When the full structure model did not converge, we pruned it by removing interactions between random factors until it did, and the results we report are all of models that converged. Mean response latencies, magnitude of priming and error rates are presented in Table 8 for the *same* and *different response* trials.

**Same responses.** The latency data analysis revealed the main effect of Type of Change to be significant,  $F(1, 228.63) = 23.582$ ,  $p < .001$ . Likewise, the main effect of Allography was significant,  $F(1, 71.91) = 20.177$ ,  $p < .001$ , and most importantly, the two-way interaction Type of Change by Allography was also significant,  $F(1, 199.58) = 10.407$ ,  $p < .001$ . Pairwise comparisons contrasting TL–Allog with SL–Allog and TL+Allog with SL+Allog using Bonferroni-Holm protection levels, revealed that while TL–Allog was significantly different from SL–Allog [ $p < .001$ ], the two +Allog conditions did not differ significantly from each other ( $p = .65$ ). Further post hoc analyses focusing on the two allographic conditions (i.e., TL+Allog and SL+Allog) showed the effects of Type of Change (i.e., TL vs. SL) to be nonsignificant,  $F(1, 143.22) = 1.050$ ,  $p = .31$ , and neither were the effects of Form of Allography,  $F(2, 237.44) = 0.699$ ,  $p = .50$ , nor those of their interaction,  $F(2, 94.12) = 0.296$ ,  $p = .74$ . In this model, the only significant effect was PrevRT,  $F(1, 1108.83) = 7.4370$ ,  $p < .006$ . Focusing on the effects of Letter Group within the two-letter substitution conditions revealed no reliable effects for Allography,  $F(1, 43.12) = 1.232$ ,  $p = .27$ , or Letter Group,  $F(1, 39.58) = 1.148$ ,  $p = .29$ . There was however a reliable effect of PrevRT,  $F(1, 1055.60) = 3.8150$ ,  $p < .05$ .

The accuracy data were submitted to a logit mixed model with the same fixed factors as before (excluding previous trial RT). The effects of Type of Change were nearly significant ( $t = -1.911$ ,  $p < .06$ ), while those of Allography ( $t = -0.698$ ,  $p = .49$ ) and the interaction between Type of Change and Allography ( $t = 1.326$ ,  $p = .18$ ) were not. Pairwise post hoc Bonferroni-Holm corrected analyses revealed there to be no difference between any two combinations of the four condition in terms of error rates. We also evaluated the effects of Form of Allography in the context of the TL+Allog and the SL+Allog conditions and found that the effects of Type of Change ( $t = -0.698$ ,  $p = .49$ ), Form of Allography ( $t = 1.515$ ,  $p = .130$ ), and the interaction between them ( $t = -0.505$ ,  $p = .61$ ) were not significant.

Finally, we calculated the Bayes factor for the interaction by comparing our main model, which included the interaction Type of Change  $\times$  Allography with a model that did not include this interaction as the denominator. The results of this analysis suggest that there was evidence for this interaction with odds equaling  $7.96 \pm 2.37\%$ . This is consistent with the results of Experiment 2 and suggests that the data provide reliable evidence for the hypothesis that Allography modulates the amount of TL priming effects in the same-different matching task in Arabic.

**Different responses.** Data from the *different response* trials were analyzed in the same way as the *same responses*. Consistent

Table 8  
*Mean Response Latencies (RT, in ms), Percent Error Rates (in Parentheses), and Magnitude of Facilitation (Priming in ms) in Experiment 3 (Same-Different Task With Nonwords)*

Response and prime type	Same	Different
1. Identity	539 (4.52)	620 (5.97)
2. TL-Allog	535 (5.00)	619 (7.58)
3. SL-Allog	582 (7.58)	626 (4.68)
TL priming effect: SL-Allog minus TL-Allog	47	8
4. TL+Allog	580 (6.45)	617 (6.45)
5. SL+Allog	591 (6.45)	608 (5.32)
6. Baseline	596 (12.42)	620 (5.48)
TL priming effect SL+Allog minus TL+Allog	11	-9

with the literature (Norris & Kinoshita, 2008), and with Experiment 2, the results revealed no significant effects of Type of Change,  $F(1, 85.59) = 0.487, p = .49$ , Allography,  $F(1, 76.81) = 1.066, p = .31$ , or their interaction,  $F(1, 240.22) = 0.768, p = .38$ . The control variable PrevRT was significant,  $F(1, 2204.52) = 63.271, p < .001$ . Pairwise comparisons between the four conditions (i.e., TL-Allog, TL+Allog, SL-Allog and SL+Allog) using the Bonferroni-Holm correction revealed no significant differences whatsoever (all  $ps \geq .1$ ).

A comparison of the two allography conditions (i.e., TL+Allog and the SL+Allog) to determine whether the different manifestations of allography modulated response time revealed no effects either of Type of Change,  $F(1, 269.20) = 1.897, p = .17$ , Form of Allography,  $F(3, 116.99) = 0.238, p = .87$ , or their interaction,  $F(2, 115.10) = 0.253, p = .78$ . The only significant effect to be found here was PrevRT,  $F(1, 1116.10) = 21.613, p < .001$ .

Error responses to Different trials were also analyzed using the same logit approach used with the *same response* trials. The effects of Type of Change ( $t = -1.940, p = .05$ ), Allography ( $t = -0.428, p = .67$ ), and their interaction ( $t = 1.472, p = .14$ ) were not significant. Similar results emerged from the analysis of the two allography conditions with Type of Change ( $t = -1.775, p = .08$ ), Form of Allography ( $t = -0.980, p = .33$ ), and their two-way interaction all failing to show any significant effects ( $t = 0.901, p = .37$ ). Similarly, the analysis of the two transposition conditions (i.e., SL-Allog and SL+Allog) revealed no significant effects for Allography ( $t = -1.102, p = .27$ ) or Letter group ( $t = -0.815, p = .42$ ).<sup>5</sup>

## Discussion

Kinoshita and Norris (2009) suggested that the same-difference matching task taps prelexical representations. If this is the case in Arabic, then the TL priming effects observed in Experiment 2 should also be found in Experiment 3. The results clearly indicate that TL priming effects in nonwords are similar to those observed with words and are significantly modulated by allographic variation, in the sense that the critical two-way interaction between Type of Change and Allography proved to be significant in both Experiments 2 and 3. Our post hoc analyses also suggest that Form of Allography (i.e., change in letter from, change in ligation, or blank space location) are treated as functionally equivalent in

terms of changing the overall appearance of the word. Transposed and substituted letter words are not perceived as more similar or more different depending on whether the experimental manipulation caused changes in letter form, letter ligation, or blank space location. These analyses further suggest that the variable Letter Group requires further investigation to determine the extent to which it may or may not modulate the effects of letter substitution.

The main conclusion one can draw from this experiment is that masked priming in the same-different task does not operate on representations higher than letters in Arabic, as claimed by Perea et al. (2011). One reason for the discrepancy between the present results and Perea et al.'s may be, as we suggested above, that they did not control for allographic variation. Another reason may be that they sometimes manipulated a *matres lectionis* letter which can be read as a vowel or consonant depending on its position in the word. The results of a recent study by Kinoshita et al. (2012) using the same-different matching task with Hebrew words and nonwords are in keeping with the outcomes of this experiment. Both that study and the present experiments indicate that provided that the influence of position-dependent allography is controlled, even when the letter transposition manipulation is applied to the root letters, TL priming effects emerge in the same-different task thus indicating that this task operates on prelexical representations.

## Combined Analyses of Experiments 1 and 2

In this section, we report an analysis of the data from the four conditions of interest (i.e., TL-Allog, SL-Allog, TL+Allog, and SL+Allog) using the *word response* data of Experiment 1 and the *same response* data of Experiment 2 to better understand the change in the pattern of priming across the two tasks. To perform this between-experiment comparison, response times for each participant were transformed into z-scores (i.e., RTs for target words were expressed as a number of standard deviations greater or less than each participant's mean) to remove differences between participants in the speed or variability of their responses (Davis, Marslen-Wilson, & Gaskell, 2002; Zwitserlood, 1989). We took the same approach as before, fitting the full structure model and pruning as necessary until the model converged. The main effects of Type of Change,  $F(1, 157.4) = 32.413, p < .001$ , and Allography  $F(1, 245.7) = 7.951, p < .005$ , were significant. Apart from the two-way interaction Type of Change by Task,  $F(1, 157.1) = 10.851, p < .001$ , neither the two-way interaction Type of Change by Allography,  $F(1, 146.0) = .736, p = .392$ , nor Allography by Task,  $F(1, 346.1) = .704, p = .40$ , nor the three-way interaction Type of Change  $\times$  Allography  $\times$  Task,  $F(1, 234.7) = 1.581, p = .21$ , was significant. The significant interaction between Type of Change and Task suggests that the effects of allographic variations are modulated by task demands. Previous experimental research corroborates this and suggests that the masked priming lexical-decision task in Arabic engages lexical access processes which project orthographic input onto internal representations that are defined particularly in terms of root morphemes (Boudelaa & Marslen-Wilson, 2005, 2015; Gwilliams & Marantz, 2015; Prunet, Béland, & Idrissi, 2000). This morphological configuration of the Arabic lexical space brings new processing demands to bear on the

<sup>5</sup> Because of a rank deficiency issue in the matrix of the fixed-effect model, the interaction term was not estimated.

implementation of the lexical-decision task in the context of Arabic: It has to be implemented on the basis of lexical information that corresponds to the root. Any manipulation that affects the root identity either by transposing or substituting its component letters as we did here will result in a new root that will not be considered by the language processor to be any more similar to the base root than any other random root. For instance, the TL root {ktb} and the substituted letter root {xjb} will not be any closer in lexical space to the base root {ktb} than the random root {hnf}. This leaves little room for TL-priming effects to emerge in Arabic. In contrast, the same-different match task operates on prelexical representations and does not engage lexical access processes hence manipulations that alter the root letters are not detrimental to TL priming effects since performance on the task is not contingent on morphological structure.

### General Discussion

The three experiments reported here provide new evidence that addresses a number of important questions in visual word recognition; in particular, whether TL priming effects in Arabic are modulated by position-dependent letter shape change (allography) and whether different processing dynamics are engaged by lexical decision and the same-different match task. In what follows we first discuss these issues in light of the new evidence our results provide, then we consider the implications of these results for current models of letter coding.

### TL Priming Effects and Allography

The purpose of this research was to determine whether allographic variation plays a role in the orthographic processing of Arabic and whether this role is modulated by task demands. Unlike the Roman alphabet (uppercase and lowercase letters) used in European languages, allographic variation in Arabic is position-dependent. Using a masked priming lexical-decision task (Experiment 1) our findings suggest that when the task engages lexical access processes, the standard TL-priming effects routinely observed in Indo-European languages are not found, nor are they modulated by the change in shape of the letter as it is transposed or substituted. In contrast, Experiments 2 and 3 using the same different match task with words and nonword, respectively, clearly show that robust TL priming effects are present in this task, and that allographic variation modulates TL priming. Priming is reduced for letters that change shape (i.e., involve allographic variation). This result is significant, not only because it is the first such finding in the literature, but also because it shows how the allographic variation in Arabic impacts on orthographic processing. As discussed earlier, [Friedmann and Haddad-Hanna \(2012\)](#) reported that letter migration errors in reading aloud in Arabic LPD (letter position dyslexia) patients are reduced for words in which letter transposition or letter substitution causes allographic changes in their overall shape. The authors attributed this finding to the position-dependent allography unique to Arabic. Our data indicate that [Friedmann and Haddad-Hanna's \(2012\)](#) results are not a product of an immature reading process specific to individuals with dyslexia relying more on "global, visual elements rather than on abstract letter representations" akin to "visual, logographic level of reading in the initial steps of learning to read" as suggested

by [Perea et al. \(2013, p. 571\)](#). Rather, their results, like ours, reflect the adaptive use of linguistic knowledge to counter perceptual uncertainty.

Our results are also consistent with the Uyghur data we mentioned above ([Yakup et al., 2014, 2015](#)). These authors acknowledged the role of position-dependent allography in letter position coding in skilled readers based on the finding that reading of "jumbled words" (words with internal letters rearranged) was modulated by position-dependent allography. [Yakup et al. \(2015\)](#) maintained that such effects would be difficult to demonstrate in Arabic even though it uses the same script as Uyghur because of its Semitic morphology and the predominantly consonantal system. Our findings in Experiment 2 and 3 on the modulation of TL priming by position-dependent allography in skilled readers of Arabic clearly shows that these are not the limiting factors.

In most languages using a Roman script, and with the exception of the first letter in a sentence or the first letter in a proper noun, allographic variation does not convey any useful information about either word identity or letter order. Consistent with this, readers appear to rely entirely on a level of letter representation that abstracts over these details. In contrast, allographic variation in Arabic conveys important information about the order of letters within a word and hence the identity of the word and, as shown by the modulation of TL priming by allography, readers successfully take advantage of that information to reduce positional uncertainty. Allographic information must necessarily be associated with letter-identity information. Therefore, Arabic readers must have access to a representation that encodes order, identity, and allographic information simultaneously. Note that this result should not be taken to imply that there is not a level of abstract letter representation in Arabic. The final level of representation driving lexical access must abstract over irrelevant visual details of the script such as variations in font or size. The critical message from the present study is that readers of Arabic are able to use information about the allographic form of letters to constrain letter order which, early on in processing, is ambiguous because of noise in the perception of letter order.

Finally, the current set of experiments provides interesting suggestions about two issues. The first is that the different manifestations of allography (i.e., change in letter form, change in letter ligation and change in blank space location with the word) appear to be equally effective as cues to letter order in the same-different task in Arabic. This finding suggests that the overall shape of the Arabic word might contribute information to constrain the visual processing of the letter string. A second suggestion relates to the effects of letter substitution which do not seem to be modulated by letter group. Specifically, SL primes in which the replaced letter kept the same basic shape as the original letter (e.g., <sup>\*</sup>يشغدون - يسعدون *yʃɣduun- ysʕduun* 'be happy') did not prove to be more effective at facilitating the target than substituted letter primes in which the replaced letter was visually different (e.g., <sup>\*</sup>يهضرون - يستررون *yhdʀruun-ystruun* 'cover'). This suggests that information about diacritical marks plays a critical role in defining letter identity and that the diacritics are processed as an integral part of the letter. At a more general level, this finding sheds new light onto the possible detailed specifications of the type of letter representation that needs to be mapped onto an 'abstract letter level' in Arabic (cf., [Perea et al., 2016](#) and [Wiley, Wilson, & Rapp, 2016](#)).

### Lexical Decision Versus Same–Different Match Task

In line with Norris and Kinoshita's (2012a) noisy channel model, we view the process of visual word recognition as a special case of general object recognition, and that letter position coding depends on the same processes as other forms of object position coding. Because perception is noisy, both the letter identity information and letter position information are initially ambiguous, but become more certain as more perceptual information accumulates.

On the surface, the assumption that the same orthographic representation is involved in lexical decision and the same–different task may seem at odds with the fact that the pattern of priming observed here in Experiment 1 and 2 were very different. Note however that our theory of masked priming based on the Bayesian Reader (e.g., Kinoshita & Norris, 2009; Norris & Kinoshita, 2008) makes it clear that priming effects are not task-invariant. According to the Bayesian Reader, perception involves Bayesian inference based on the accumulation of noisy evidence, with the hypothesis for which evidence is accumulated being determined by the goal of the task. In the context of masked priming a second critical assumption is that the prime and target are processed as a single perceptual object, and evidence from both the prime and target continuously updates the posterior probability of the hypothesis required to perform the task.

In lexical decision, the reader's task is to decide whether the input matches any item in the lexicon (i.e., it is "a word"). More specifically, the task is to decide whether the input is more likely to be a word than a nonword. The reader is assumed to continuously sample from the input so as to home in on a sufficiently small region of lexical space to determine whether the input is more likely to be a word than a nonword. Accordingly, the evidence needed to make a lexical decision is expected to depend on the distributional characteristics of the lexical space. Specifically, in Arabic, the lexical space is structured around the tri-consonantal root system and the word pattern reflecting the standard Semitic morphology. As mentioned earlier, the transposition of any two letters of any Arabic root generates a hit (i.e., another existing root) more than 50% of the time, and most importantly, it preserves the typical Semitic morphological structure with a clearly identifiable three letter pseudoroot interleaved with an existing word pattern. This then is why, unlike English and other European languages written in the Roman alphabet, TL priming effects are absent in Arabic in lexical decision. The pervasive morphological structure of Arabic means that, any point in lexical space will be dense. Consequently, as with high-N words in English, there is little scope for observing masked priming effects by orthographic neighbors.

The situation with the same–different match task is different. The decision, in this case, does not need to factor in information about all the words in the lexicon, only about the referent. As a consequence, the lexical status (whether the referent/target is a word or a nonword) does not come into play, and as originally demonstrated by Kinoshita and Norris (2009) with nonwords written in the Roman alphabet, reliable identity and TL priming effects are observed, as was found with the Arabic nonwords in the present Experiment 3. Similarly, in contrast to lexical decision, the density of the lexical space does not come into play; all the reader needs to do is accumulate enough evidence to compare the likelihood that the target has the same form as the referent with the

likelihood that it is different. This decision is based on the same orthographic representation consisting of letter identity and letter position information that serves as the input to lexical access, but the same–different decision does not concern the words in the lexicon, only whether it matches the referent string, in terms of the letter identities contained in the referent string and their order. Thus our results showing robust TL priming effects for Arabic words and nonwords in the same–different task, and contrary to the claim made by Perea et al. (2011), clearly point to the fact that the same–different match task taps the same—prelexical—level of representation in Arabic as it does in English or Hebrew, and that performance in this task is not modulated by morphological structure. Finally, at this prelexical level, the TL prime containing allographic variation (TL+Allog condition) provides greater certainty that the letter order is different from the referent/target string, resulting in reduced TL priming effects relative to the TL–Allog condition, that is, the modulatory effect of allographic variation in TL priming of Arabic words and nonwords.

We also note that the two aspects of the present study illustrate how cross-linguistic research contributes to the debate over a "universal model of reading," spurred on by Frost (2012). Coltheart and Crain (2012) suggested that there is no property shared by all of the world's writing systems. On the other hand, Kessler and Treiman (2015) pointed out that the fact that "writing is designed to be taken in by the eye leads to some characteristics that are essentially universal in modern writing" (p. 11). In this context, it may be noted that the majority of contemporary writing systems denote the order of letters in a linear spatial arrangement, regardless of whether it is written from left to right (as in English and other European languages), or right to left (as in Hebrew and Arabic) or vertically with logograms or logographs (as in Chinese or Japanese) the edge letter/logogram is the first letter/logogram, the adjacent letter is the second letter/logogram, and so on. Robust TL priming effects in the same–different task have now been reported for Arabic, as well as for many other languages including Hebrew, and European languages. This is consistent with our view (Norris & Kinoshita, 2012b) that TL priming effects originate in the uncertainty in the perception of letter order, due to the limits of precision in the perception of the spatial location of closely arranged objects. In contrast, the modulatory effect of allographic variation in TL priming observed in Experiments 2 and 3 sets Arabic apart from other languages. It is important to note that languages differ in many ways, and our results showed that it is not the Semitic morphology but the position-dependent allography in Arabic that is responsible for the modulation of TL priming effects in the same–different task. Taken together these two aspects of the results reinforce our view that in modeling orthographic processing, both language-universal (perceptual) processes and the exact nature of language-specific information used in the task need to be considered.

### Theoretical Implications

In this final section, we consider how current models of letter coding might accommodate the kind of allographic effects we have documented here. We first consider the spatial coding model SOLAR (Davis, 2010). On this view, the relative position of spatially distributed items is coded in terms of an activation gradient decreasing across letter position with the highest values



being assigned to the initial letter of the string and the lowest to the last. In the Arabic word *يسعدون* *yisʕduun be happy*, the first letter *ي* has the highest value, *س* the second value, *ع* the third and so on until the final letter *ن* which will be assigned the lowest value. The model determines the degree of match between *يسعدون* and its TL-Allog prime *يعسدون* for instance by computing a Gaussian function that reflects letter position uncertainty. These Gaussian functions are then summed up to compute a superposition function whose amplitude will correspond to the match value. A large amplitude indicates a perfect match, whereas a low amplitude is a sign of a poor match value. One further characteristic of SOLAR is that the initial and final letters are explicitly tagged to capture the fact that they are more accurately coded than internal letters at least in Indo-European languages. In the context of Arabic, this initial-final letter tagging procedures will need to be expanded to tag all letter allographs as *initial*, *medial*, and *final* if the effects of allography in Arabic are to be captured. Given this modification, the spatial pattern to code the TL-Allog pair *يسعدون-يعسدون* will match perfectly because the transposed letters *س* and *ع* will be tagged as medial allographs in both cases. The spatial pattern coding for the TL+Allog pair *يسعدون-يسدون*, on the other hand, will have a lower match value because there is a mismatch between *ع* initial in the prime and *س* medial in the target. A similar argument can apply to the substituted letter condition where a medial *س* is replaced by a medial *ش* and a medial *ع* by a medial *غ* in the SL-Allog pair *يسعدون-يشغدون* thus preserving the overall shape of the word in the SL-Allog condition and leading to a higher match score than the SL+Allog pair *يسعدون-يسزرون* where the medial, but nonconnecting letter *ز* and the final letter *ر* respectively, substitute for the medial letter *ع* and the medial/final nonconnecting letter *د*. Thus tagging of letter allographs as initial, medial, final and isolated could in principle allow SOLAR to accommodate the presence of allographic effects in the same-different match task. What is less clear, however, is the ability of the model to capture the absence of TL-priming and allographic effects in the lexical-decision task. Future developments of the model will need to address this issue.

A second equally influential class of models is the open-bigram model (Grainger & van Heuven, 2003; Grainger & Whitney, 2004). In the version developed by Grainger and Van Heuven (2003), the model consists of three levels: An *alphabetic array*, which is a bank of detectors that simultaneously process all characters in the input and provides a retinotopic map of all characters in a given string. This information is then fed to the second level of the model, *the relative position map*, which consists of open bigrams that code the relative position of the letters in the string abstracting over surface form variations such as shape, size, and location of the stimulus. The final level of the model is the *orthographic word* where all words for which spelling is known are represented. On this account the TL-Allog prime *يسعدون* would have the open bigrams *يع*, *يس*, *يد*, *يو*, *ين*, *يسد*, *يسع*, *يسو*, *يسن*, *يسدو*, *يسدن*, *يسدون* and the TL+Allog prime *يسدون* will have the open bigrams: *يسد*, *يسع*, *يسو*, *يسن*, *يسدون*, *يسدو*, *يسدن*, *يسدون*. Accordingly, each of them shares 14 out of its total 15 open bigrams with the target word 'يسعدون'. Because the two types of primes show the same amount of open bigram overlap with the target, they should be equally effective on this account in facilitating the target word. This, as we saw above, is clearly not the case. The same holds true of the SL-Allog *يشغدون*

and the SL+Allog *يسزرون*. With each of them sharing six of its 15 open bigrams with the target *يسعدون*, we are again led to expect comparable priming behaviors contrary to what we actually observe. In sum, although it is true that the model rightly predicts less priming in the substituted than the transposed letter conditions, it clearly falls short of predicting the modulatory effects of allography. One way around this would be to introduce an intermediate level of representation between the alphabetic array and the relative position map to capture allographic forms. On this scenario the TL-Allog prime *يسعدون* will share 14 open allographic bigrams with the target *يسعدون*, whereas the TL+Allog prime *يسدون* will share only 9 such bigrams with the same target, rightly accommodating less facilitation in the latter condition. The same applies to the SL-Allog and the SL+Allog case where the introduction of an intermediate level of allographic representation will allow the model to capture the modulatory effect of surface form variation because the SL+Allog will share fewer of their allographic bigrams with the target than SL-Allog. In sum then, the introduction of an intermediate allographic level of representation allows the open bigram model to accommodate the present results. However, despite this modification, and just like SOLAR, the open bigram model remains unable to offer an account for why TL-priming effects can be made to come and go in Arabic depending on the task used.

The final family of models we consider is the class of models that assume noisy perception of letter order, including the overlap model (Gómez et al., 2008) and the noisy-slot Bayesian Reader (Norris, Kinoshita, & van Casteren, 2010) and the noisy channel (Norris & Kinoshita, 2012a) model. In itself, the idea that perception of order is noisy would be unable to explain the effect of allography. Allography should have no effect on the noise in the input. There must be some additional mechanism to take account of the constraint that allography places on letter order. In the noisy-channel Bayesian Reader, the model accumulates noisy samples from the input and uses them to construct a posterior distribution of item identity and order; which items are present, and in which order they appear in. An optimal Bayesian system should use all available perceptual information to determine letter identity and order. Allography provides a potentially important source of information to constrain the order in which letters are likely appear. That is, once allographic information becomes available, it should modify the prior expectation of the order of letters in the word. This conceptualization allows the Bayesian reader to naturally capture allographic effects in Arabic.

## Conclusions

The present paper provides evidence for the first time that TL-priming effects occur in Arabic and that they are modulated by allographic variation. The paper further demonstrates that these effects can be made to come and go depending on task demands. Collectively, these results pose a challenge to various letter-position coding models that explain TL priming effects in terms of specialized orthographic representations (e.g., SOLAR, open bigrams), but can be satisfactorily accommodated by models that assume the noisy perception of letter order (e.g., noisy slot Bayesian Reader). Future simulation work will need to be carried out to further refine our claims about orthographic coding schemes and their cross-linguistic implications.

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(Appendices follow)

## Appendix A

Table A1  
 Stimuli Used for the Word Response in Experiment 1 and the Same Response in Experiment 2

Target	TL – Allog	TL + Allog	SL – Allog	SL + Allog	Baseline
تتفان tuNaF~i*aani يُتفدون	تتفان tuNaF~i*aani يُتفدون	تتفان tuNa~iFaani يُتفدون	تتفان tuGaB~i*aani يُتفدون	تتفان tuNaD~iGaani يُتفدون	استقبش istaQBa\$a تتفدون
ya\$Ha*uuuna يُتفدون	ya\$Ha*uuuna يُتفدون	ya\$aHuuna يُتفدون	yaTXa*uuuna يُتفدون	ya\$RaLuuna يُتفدون	taDZuQiina انصشفا
yaJHaDuuna يُتفدون	yaJHaDuuna يُتفدون	yaJDaHuuna يُتفدون	yaZLaDuuna يُتفدون	yaJ*aQuuna يُتفدون	inSaFa\$a انبتسما
yastaVMiRuuna يُتفدون	yastaVMiRuuna يُتفدون	yastaVRiMuuna يُتفدون	yastaXSiRuuna يُتفدون	yastaVHiFuuna يُتفدون	inBaDaStumaa تتفدون
yataTaL~aEaani يُتفدون	yataTaL~aEaani يُتفدون	yataTaE~Laani يُتفدون	yataGaM~aEaani يُتفدون	yataTaQ~aZaani يُتفدون	taVta > iDuuna اُتفها
yaHSuDuuna يُتفدون	yaHSuDuuna يُتفدون	yaHDuSuuna يُتفدون	yaJQuDuuna يُتفدون	yaHBuZuuna يُتفدون	aXLaVuhaa تتفدون
yataEaH~aDuuna يُتفدون	yataHaE~aDuuna يُتفدون	yataEaD~aHuuna يُتفدون	yataGaL~aDuuna يُتفدون	yataEaV~aQuuna يُتفدون	tatRaN~aFiina استكفمه
yanTaLiQaani يُتفدون	yanLaTiQaani يُتفدون	yanTaQiLaani يُتفدون	yanKaFiQaani يُتفدون	yanTaXiDaani يُتفدون	istaKGaMahum تتفدون
yaSEaDuuna يُتفدون	yaSEaDuuna يُتفدون	yaSDaEuuna يُتفدون	ya\$GaDuuna يُتفدون	yaSHaJuuna يُتفدون	tataNaaVaJu نُتفك
yaNBu*uuuna يُتفدون	yaNBu*uuuna يُتفدون	yaN*uBuuna يُتفدون	yaTFu*uuuna يُتفدون	yaNDuZuuna يُتفدون	nuHaaSiQuka استكفون
yaKNuZuuna يُتفدون	yaKNuZuuna يُتفدون	yaKZuNuuna يُتفدون	yaJBuZuuna يُتفدون	yaK\$uSuuna يُتفدون	istaJVaRa اشككطا
yaQtaSiDuuna يُتفدون	yaQtaSiDuuna يُتفدون	yaQtaDiSuuna يُتفدون	yaXtaDiDuuna يُتفدون	yaQta*i\$uuna يُتفدون	i\$taKataTaa تفصان
yuN\$DiDuuna يُتفدون	yuN\$DiDuuna يُتفدون	yuNDi\$uuna يُتفدون	yuBSiDuuna يُتفدون	yuNQiJuuna يُتفدون	taXFiSaani استككطا
yataBaXTaRuuna يُتفدون	yataXaBTaRuuna يُتفدون	yataBaRTaXuuna يُتفدون	yataQaFTaRuuna يُتفدون	yataBa*TaJuuna يُتفدون	istaKJaTaa اُتفخت
yaHSuLaani يُتفدون	yaHSuLaani يُتفدون	yaHLuSaani يُتفدون	yaJZuLaani يُتفدون	yaHQzZaani يُتفدون	iJtaZaXat تتفدون
yataFaQ~aDaani يُتفدون	yataFaQ~aDaani يُتفدون	yataFaD~aQaani يُتفدون	yataEa\$~aDaani يُتفدون	yataFa\$~aEaani يُتفدون	tataFaX~aJaani تتفدون
yaNZuRaani يُتفدون	yaZaNuRaani يُتفدون	yaNRuZaani يُتفدون	yaJGuRaani يُتفدون	yaNLU\$Saani يُتفدون	nataTaaKaLu نُتفطاش
yuLHiDuuna يُتفدون	yuLHiDuuna يُتفدون	yuLDiHuuna يُتفدون	yuNXiDuuna يُتفدون	yuLRI*uuuna يُتفدون	nataXaaZa\$a اشككطتي
yaHtaJiZaani يُتفدون	yaHtaJiZaani يُتفدون	yaHtaZiJaani يُتفدون	yaBtaQiZaani يُتفدون	yaHtaRiTaani يُتفدون	a\$HaZtini تفصان
yuEaT~iLaani يُتفدون	yuTaE~iLaani يُتفدون	yuEaL~iTaani يُتفدون	yuVaB~iLaani يُتفدون	yuEaR~iXaani يُتفدون	tuFSi\$ina اُتفذمت
yuFaDiLaani يُتفدون	yuDaFiLaani يُتفدون	yuFaLiDaani يُتفدون	yuFaBiLaani يُتفدون	yuFaHiJaani يُتفدون	inTa*aMat اُتففت
yaSHaRuuna يُتفدون	yaHSaRuuna يُتفدون	yaSRaHuuna يُتفدون	yaVKaRuuna يُتفدون	yaS*aluuna يُتفدون	inTaFaVat استكط
yuNKiRuuna يُتفدون	yuKNiRuuna يُتفدون	yuNRiKuuna يُتفدون	yu\$SiRuuna يُتفدون	yuNSiGuuna يُتفدون	istaBLaZa انككطا
yataTaH~aRuuna يُتفدون	yataHaT~aRuuna يُتفدون	yataTaR~aHuuna يُتفدون	yataZaX~aRuuna يُتفدون	yataTaQ~aBuuna يُتفدون	inJaHaQataa تتفدون
yu\$aEWi*aani يُتفدون	yuEa\$Wi*aani يُتفدون	yu\$aWEi*aani يُتفدون	yuSaGWi*aani يُتفدون	yu\$aBLi*aani يُتفدون	tuJaQHITuuna استككنت
yaNtaQiDuuna يُتفدون	yaNtaQiDuuna يُتفدون	yaNtaDiQuuna يُتفدون	yaXtaViDuuna يُتفدون	yaNtaRiXuuna يُتفدون	istaLZa > at انككطا
yataEV~aRuuna يُتفدون	yataEV~aRuuna يُتفدون	yataER~aVuuna يُتفدون	yataJT~aRuuna يُتفدون	yataEZ~aTuuna يُتفدون	inBXaJataa اُتفها
yataHaF~aZuuna يُتفدون	yataFaH~aZuuna يُتفدون	yataHaZ~aFuuna يُتفدون	yataLaT~aZuuna يُتفدون	yataHaD~aDuuna يُتفدون	aQtaLiRuhaa نُتفصمه
yaDtaHiDuuna يُتفدون	yaHtaDiDuuna يُتفدون	yaDtaDiHuuna يُتفدون	yaStaKiDuuna يُتفدون	yaDtaQiEuuna يُتفدون	naStaSmiHuhu تتفدون
yuNQi*uuuna	yuQNi*uuuna	yuN*iQuuna	yuHTI*uuuna	yuNKQiXuuna	tuZViYaahu

(Appendices continue)

Table A1 (continued)

Target	TL-Allog	TL+Allog	SL-Allog	SL+Allog	Baseline
ألهما aLHaManaa ألصقت aLSaQat أفشلنا aF\$alLnaa أشعلتها a\$EaLathaa أغضبني aGDaBanii امتعضت iMtaEaDat ألظها aLTuMuhaa ألظها aLFuZuhaa أفعمته aFEaMtuhu أخفقوا aXFaQuu أظنوا iZEaNuu أظنه aTEaNuhu اعتصموا iEtaSaMuu أنشئت aNEa\$at ارتحلت iRtaHaLat أعقته aETaQahu أعشقاها aE\$aQuhaa اعتكفت iEtaKaFat أضعت aDEaFat اغتنبت iGtaBaTat اغتصموا iGtaSaBuu أغلقتنا aGLaQnaa أغضت aGMaZat أبعر uBaEViru ارتجلت iRtaJaLat ارتطمت iRtaTaMat ارتضينا iRtaDaYnaa أغفيا aGFaYaa اضغطوا iDGaTuu أعسكر uEaSKiRu	ألهمنا aLMaHanaa ألصقت aLQaSat أفشلنا aFLa\$anaa أشعلتها a\$LaEathaa أغضبني aGBaDanii امتعضت iMtaDaEat ألظها aLMuTuhaa ألظها aLZuFuhaa أفعمته aFMaEtuhu أخفقوا aXQaFuu أظنوا iZNaEuu أظنه aTNaEuhu اعتصموا iEtaMaSuu أنشئت aNSaEat ارتحلت iRtaLaHat أعقته aEQaTahu أعشقاها aEQa\$uhaa اعتكفت iEtaFaKat أضعت aDEaEat اغتنبت iGtaTaBat اغتصموا iGtaBaSuu أغلقتنا aGQaLnaa أغضت aGZaMat أبعر uEaVEiru ارتجلت iRtaJaLat ارتطمت iRtaTaMat ارتضينا iRtaYaDnaa أغفيا aGYaFaa اضغطوا iDTaGuu أعسكر uEaKSiRu	ألهما aHLaManaa ألصقت aSLaQat أفشلنا aF\$aLanaa أشعلتها aE\$aLathaa أغضبني aDGaBanii امتعضت iEtaMaDat ألظها aTLuMuhaa ألظها aFLuZuhaa أفعمته aEfaMtuhu أخفقوا aFXaQuu أظنوا iEzaNuu أظنه aETaNuhu اعتصموا iStaEaMuu أنشئت aENa\$at احتزلت iHtaRaLat أعقته aTEaQahu أعشقاها aE\$aQuhaa اكتعفت iKtaEaFat أضعت aDLaFat ابتغطت iBtaGaTat اصتصموا iStaGaBuu ألغقتنا aLgaQnaa أغضت aMGaZat أبعر uEaBViru اجترلت iJtaRaLat اطنرمت iTtaRaMat اضنرنا iDtaRaYnaa أغفيا aFGaYaa اغضطوا iGDaTuu أسعكر uSaEKiRu	الضشنا aLDa\$naa ألظت aLDaGat أففظنا aFSaZanaa أشقتنا a\$QaVathaa أغمشني aGMa\$anii امتعضت iMtaSaZat ألحها aLHuVuhaa ألنضها aLNUduhaa أفجظته aFJaZtuhu أخمتوا aXMaTuu أظنوا iZGaJuu أظفه aTQaLuhu اعتشظوا iEta\$aZuu أنثت aNGaVat ارتثت iRtaVaBat أعقه aENaXahu أعجها aEbaXuhaa اعتجظت iEtaJaZat أضلبت aDLaBat أعثت iGtaVaNat اغتظقوا iGtaTaQuu أغشظنا aG\$aSnaa أغلت aGLaHat أبقر uBaQNiru ارتنصت iRtaNaSat ارتعتك iRtaEaKat ارتظنا iRtaXaTnaa أغما aGMaJaa اضلقوا iDLaQuu أعضر uEaLDiRu	أدجمنا aDJaManaa أرتقت aRvaQat أرضنا aRDaLanaa أفذلها aFDaLathaa أذليني a*LaBanii ابتعضت iBtaDaDat أدظها aDZuMuhaa أنزظها aNZuZuhaa أظز مته aTzaMtuhu أثذقوا a\$aQuu أزخوا iZxaNuu أكذته Ak*aNuhu أشذموا i\$taDaMuu أذثت aZKa\$at أبظلت iBtaZaLat أذغه aDGaQahu أذتها aDvaQuhaa أزذفت iZta*aFat أبرفت aBRaFat أمنذطت iMta*aTat أجدبوا iJtaDaBuu أزظقتنا aZTaQnaa أذضت aDZaZat أبوغر uBaWGiru أكتخت IKtaJaLat أهصمت iHtaSaMat أختجينا iXtaJaYnaa أركيا aRkaYaa أذظوا iDZaTuu أزكر uBaZKiRu	تندفني tanDaNiQii ينبث yanBaTiVu يبحون yaVHaJuuna يكتجون yaKtaJiHuuna نتابخ nataTaaBaXu يقفون yaQFaKuuna يدعجه yaDGaJuhum تجظهنه taJTaHunii نصمها naHSuMuhaa تندبن taNVuDiina تنبجا tanBaViJaa تظشك taZ\$uKuka نستظبكي nastaTsiBukii تحبيا taHaY~aBaa يجفضنا yaJFuDunaa أذشخي taHa\$~aXii تلوهوا taLaW~aHuu تظكها nuTaY~iKuhaa تظدمت taZaD~aSat نيزعها naBZuEuHaa ينلشونه yaNLu\$uunah نخدهم naXDaHuhum نذشرك na*\$uRuka ينزخه yaNZaXuhu تدازن tatDaa > aZu نجاوكة nuJaaWiKuhu نجشهم naJ\$uTuhum تجره taJQuRuhu تنزني taN>aZunii تتخذ natVaX~aDu

Note. Stimuli are given in Arabic and in modified Buckwalter transliteration with the manipulated root letters in upper case.

(Appendices continue)

Table A2  
*Stimuli Used for the Nonword Response in Experiment 1*

Target	TL-Allog	TL+Allog	SL-Allog	SL+Allog	Baseline
يعفزون	يفعزون	يعفزون	يظفزون	يعرزون	نشد هم
yaEFuDuuna	yaFEu <u>u</u> uuna	yaE <u>u</u> Fuuna	yaZBu <u>u</u> uuna	yaERuZuuna	naL\$SaDuhum
يظهلان	يهظلان	يظهلان	يجضلان	يظلز ان	احصكي
yuZaH~iLAni	yuHaZ~iLAni	yuZaL~iHAni	yuJaD~iLaani	yuZaD~iZaani	aHDaKaTii
يلهرون	يهلرون	يلهرون	ييشرون	يلجفون	تستندق
yuLHiRuuna	yuHLiRuuna	yuLRiHuuna	yuS\$iRuuna	yuLJiQuuna	tasta* <u>Ni</u> Qu
يقفثرون	يقفثرون	يقفثرون	يقفثرون	يقفثرون	تستاقون
yataQaHVaRuuna	yataQaHVaRuuna	yataQaVRaHuuna	yataJaQBaRuuna	yataQaVBaHuuna	tasta > GiFuuna
يسجرون	يسعجرون	يسجر عون	يسلثرون	يسجطكون	تتقاجدن
yuSaJEiRuuna	yuSaEJiRuuna	yuSaJRiEuuna	yuSaLViRuuna	yuSaJTiKuuna	nataQaJDaNu
يغلرون	يغرون	يغلرون	يشظرون	يغبكون	تطاعشنه
yaGLaRuuna	yaLGaRuuna	yaGRaLuuna	ya\$ZaRuuna	yaGBuKuuna	iKEaa\$un
يعطرونه	يعفطرونه	يعطرونه	يعمكثرونه	يعملظوننه	تخلزانه
yuEaTiQiRuunahu	yuEaQTiRuunahu	yuEaTRiQuunahu	yuEaKSiRuunahu	yuEaTNiZuunahu	tuFaLiBiZaanihi
يخرها	يخرها	يخرها	يضرها	يخشها	انحصخت
yaXKuRuhaa	yaKXuRuhaa	yaXRuKuhaa	yaDQuRuhaa	yaXSuTuhaa	inHaDaXat
تقيدجت	تقيدجت	تقيدجت	تقيدجت	تقيدجت	يخلصها
taBaQDaJat	taQaBDaJat	taBaJaDat	taXaFdaJat	taBaQHaFat	yuXaL\$SiFuhaa
يتكجرون	يتكجرون	يتكجرون	يتقرون	يتجلظون	أبردهم
yuTaJKiZuuna	yutaJKiZuuna	yuTaJZiKuuna	yuTaBQiZuuna	yuTaJLiZuuna	uBaRDiQuhum
يتنجبون	يتنجبون	يتنجبون	يتنجبون	يتنجبون	أحفطه
yataTaBJa <u>u</u> uuna	yataTaBJa <u>u</u> uuna	yataTaB <u>a</u> Juuna	yataTaHQa <u>u</u> uuna	yataTaBVaKuuna	uHaFNiJuhu
يجسدون	يجسدون	يجسدون	يجطكون	يجعلون	تضدشان
yuJaESiDuuna	yuJaSEiDuuna	yuJaEDiSuuna	yuJaTKiDuuna	yuJaELiBuuna	tuBADDi\$Saani
يتحنج	يتحنج	يتحنج	يتسج	يتحنج	تتكلمان
yataHaNa <u>a</u> Ju	yataHaNa <u>a</u> Ju	yataHa <u>Na</u> Ju	yataSaB <u>a</u> Ju	yataHaNTaJu	tuNaKLiSaani
يحقلون	يحقلون	يحقلون	يهدلون	يخصصون	أطفيهم
yuHa <sup>Q</sup> iLuuna	yuQaH <sup>i</sup> Luuna	yuHa <sup>Q</sup> iLuuna	yuHaSDiLuuna	yuHaQSiTuuna	uTaF\$SiBuHum
تجتظان	تجتظان	تجتظان	تجتظان	تجتظان	استشغت
taJtaLiZaani	taLtaJiZaani	taJtaZiLaani	taJtaKiFaani	taJtaLiRaani	istaQ\$SaGat
تغيزست	تغيزست	تغيزست	تطهرست	تغفلست	يتكشطن
taGaBZaSat	taBaGZaSat	taGaBSaZat	taTaHzaSat	taGaFLaSat	yataKa\$TaNu
يمتضان	يمتضان	يمتضان	بيتلان	يمتضان	استظنجت
yaMtaDiLaani	yaMtaDiLaani	yaMtaLiDaani	yaBtaAiLaani	ya\$taDiRaani	istaZNaJat
يخلرون	يخلرون	يخلرون	يهورون	يخصصون	اشلها
yaXLuRuuna	yaLXuRuuna	yaXRuLuuna	yaHDuRuuna	yaXDuKuuna	a\$LaHahaa
يضعجان	يضعجان	يضعجان	يضعفان	يضعفان	تيسدون
yaDaNjiLaani	yaDaNjiLaani	yaDaNLiJaani	yaDQaFiLaani	yuDaNaDi <u>a</u> ani	tuBaSEiDuuna
يتعظرون	يتعظرون	يتعظرون	يتشحزون	يتعظرون	اكصفها
yataEaTZaFuuna	yataTaEzaFuuna	yataEaZTaFuuna	yata\$HaZaFuuna	yataEaQLaFuuna	uKaSNiFuhaa
يتعدكتان	يتعدكتان	يتعدكتان	يتضدتان	يتعلجان	نجلبهم
yataEaKDataani	yataKaEDataani	yataEaDKataani	yataNaDDataani	yataEaLJataani	nuQaJLiBuhum
تشلطان	تشلطان	تشلطان	تجكحان	تشدزان	ارتخبني
tu\$LiZaani	tu\$LiZaani	tu\$ZiLaani	tuJKiHaani	tuSDiZaani	iRtaXibii
يفلسون	يفلسون	يفلسون	يفلسون	يفلسون	اجتقتا
yuFaLDiSuuna	yuFaLDiSuuna	yuFaLDiSuuna	yuQaSDiSuuna	yuFaSTiSuuna	iJtaDaQataa
يقطرون	يقطرون	يقطرون	يقصرون	يقبضون	ابتخطوا
yaQLaTiR~uuna	yaQLaRiT~uuna	yaQLaRiT~uuna	yaQSaJiR~uuna	yaQLaBiD~uuna	iBtaXaTu
يقططان	يقططان	يقططان	يقعان	يقنجان	أحزجوا
yuQaTiLaani	yuQaTiLaani	yuQaLiTaani	yuQaENiLaani	yuQaJDiNaani	iHJaZiDuu
تقظرون	تقظرون	تقظرون	تقظرون	تقيلون	ابتطسو
tuQaBZiRuuna	tuQaZBiRuuna	tuQaBZiRuuna	tuQaLJiRuuna	tuQaBHiLuuna	iBvaTiSuu
يتشلغان	يتشلغان	يتشلغان	يتشسغان	يتشندران	أكفرهما
yata\$aNLaGaani	yata\$ALNaGaani	yata\$ANLaGaani	yata\$H\$SaGaani	yata\$ANdaRaani	uKaFXiRuhumaa
يكثرون	يكثرون	يكثرون	يكثرون	يكثرون	تتجلبون
yaKVaHiR~uuna	yaVKaHiR~uuna	yaKVaHiR~uuna	yaKTAJiR~uuna	yaKVaFiT~uuna	tatJaLbaDuuna
يهفخان	يهفخان	يهفخان	يهشلان	يهفزان	أشذمتا
yuHaFXiLaani	yuHaXFiLaani	yuHaLiXaani	yuHaB\$iLaani	yuHaFRiZaani	a\$ <sup>u</sup> aMaTaahu
بيظله	بيظله	بيظله	بيظله	بيظله	أعسفه
yuBaZZiLuhu	yuZaBZiLuhu	yuBaZZiLuhu	yuQaVZiLuhu	yuBaZQiLuhu	uGaSFiQuhu

(Appendices continue)

Table A2 (continued)

Target	TL-Allog	TL+Allog	SL-Allog	SL+Allog	Baseline
أعجبها uEaJ~iQuhaa أغلها aGLuNuhaa أطلشت aTLa\$at أحلها aHLu\$uhaa أطنها uLaT~iNuha أعصمها uEaS~iZuhum الضقوا iLDaQuu أعشها aE\$uJuhaa النتهم uLaNiVuhum أغظها uGaN~iZuhaa أغظنه uGaT~iNuhu أشصلتها a\$LaStuhaa أطلشها aZLu\$uhaa أطغشت aZGa\$at أعطت aETaZat أعجوا aGTiJuu أغظهم aGVuLuhum أعشني aE\$SaDanii أطغضت aTGaZat أكلها aKLaTuhaa أشعضنا a\$EaDna أهلها aHLuDuhaa أعتمها uEaVBiMuhaa أعتمها aE\$VaMuhaa أيلخوا aYLaXu أعصها aEJu\$uhaa ارتضت iRtaDaNat أضعها aDEaQuhaa أعتمهم uEaLiVuhum أغظت aGNaTat	أعجبها uEaQ~iJuhaa أغلها aGNuLuhaa أطلشت aT\$aLat أحلها aH\$uLuhaa أطنها uLaN~iTuha أعصمها uEaZ~iSuhum القضوا iLDaQuu أعشها aEJu\$uhaa النتهم uLaViVuhum أغظها uGaZ~iNuhaa أغظنه uGaN~iTuha أشصلتها a\$SaLtuhaa أطلشها aZ\$uLuhaa أطغشت aZ\$aGat أعطت aEaZat أعجوا aGJiTu أغظهم aGLuVuhum أعشني aE\$SaDanii أطغضت aT\$aGat أكلها aKLaTuhaa أشعضنا a\$DaEna أهلها aH\$uLuhaa أعتمها uEaVBiMuhaa أعتمها aE\$MaVuhaa أيلخوا aYXaLu أعصها aEJu\$uhaa ارتضت iRtaNaDat أضعها aDQaEuhaa أعتمهم uEaViVuhum أغظت aGTaNat	أعجبها uJaE~iXuhaa أغلها aLGuNuhaa أطلشت aL\$aLat أحلها aLHu\$uhaa أطنها uTa~LiNuha أعصمها uSaE~iZuhum اضلقوا iDLaQuu أعشها aE\$uGuhaa النتهم uNaLiVuhum أغظها uNaG~iZuhaa أغظنه uTaG~iNuhu أشصلتها AL\$aStuhaa أطلشها aLZu\$uhaa أطغشت aGZa\$at أعطت aEaZat أعجوا aTGiJuu أغظهم aVGuLuhum أعشني aE\$aDanii أطغضت aGTaZat أكلها aLKaTuhaa أشعضنا aE\$aDna أهلها aLHuDuhaa أعتمها uVaEBiMuhaa أعتمها aVEaMuhaa أيلخوا aLYaXu أعصها aJEU\$uhaa اضترنت iDtaRaNat أضعها aEDAQuhaa أعتمهم uLaEiVuhum أغظت aNGaTat	أعصمها uEaZ~iSuhaa أعصها aESuVuhaa أطقت aT\$aQat أعجبها aHJaTuhaa أظبها uLaZ~iBuha أعقبها uEak~i>uhum الطغوا iL\$aQuu أعظها aE\$uQuhaa الظجم uLaZiJuhum أغعبها uGaF~iEuhaa أغيبه uGaJ~iBuhu أشكعبها a\$KaEtuhaa أطبها aZBuDuhaa أطفت aZBaFat أعكت aEKaNat أغصوا aGLiSuu أعصمهم aG\$uSuhum أعصكي aE\$SaKanii أطجت aT\$aJat أعشها aKEa\$uhaa أهجبها aHJuQuhaa أعجبها uEaJBiMuhaa أعجبها aETaJuhaa أيطكوا aYTaKuu أعصها aEMUGuhaa ارتقت iRtaQaJat أضكبها aDKaJuhaa أعصمهم uEaFiDuhum أعظت aG\$SaHat	أذرقها uDaZ~iQuhaa أرذنها aR\$uNuhaa أذشت aD\$a\$at أزقتها aZQu\$uhaa أخذنها uHa*~iNuha أزرظهم uZaR~iZuhum ادرقوا iDRaQuu أذغها a\$DuGuhaa أذعهم aDEaVuhum أرظها uRaD~iZuhaa أذنه uVaD~iNuhu أذقصتها aDQaStuhaa أذقتها aDQu\$uhaa أحزشت aHZa\$at أزمظت aZMaZat أذغوا a\$GiJuu أزرلهم aZRuLuhum أذرصني aDRaDanii أقزضت aQZaDat أبزظها aBZuTuhaa أدخضنا aDXaDna أزظها aZDuZuhaa أذرمها uQa*BiMuhaa أذرمها a\$RaMahaa أخذخوا AH*aXu أزرصها aZRuSuhaa أقتشت iQtaSaNat أطرظها aTZuQuhaa أزقتهم uZaQiVuhum أوزظت aWZaTat	ينطكيه yanTaKiBuhu تظفان tuDaZ~iFaani تقتس tanQa\$SiSu يحصون yaHNiSuuna ياسجهم ya > SuJuhum تيكلن tuYaKLinu نجزظه naJZuZuhu يتلفظن yataLaF~aTna نجعظه naJtaGiTu تشتاؤون ta\$>aVuuna نذره naD*uZuhu نقذهم naQFu*Uhum تذجون taD*Juuna تهاذقت taHaa*Qat ينثخون yaNVuXuuna تلاظمت taLaaZa\$at يحدون yuBHiDuuna يكخطها yakXuTuhaa نمشه nuS > i\$uhu يشدون yaB\$Duuna تكجطين taKJuTiina يتجنوق yat~aJiNuuQa أقنبها yaSaB\$RiJaani نجافته nuJaaFiTu تحدزين taH\$DuZiina نقالنهم nuQaaLiVuhum يلاديه yaLaaDiBuhu نظاقبه nuZaaQiBuhu تحسنت taHaS~aVat تمظبوا tuM\$ZiBuu

Note. In the appendices, the asterisk (\*) represents the Arabic letter ذ and the tilde (~) represents gemination.

(Appendices continue)

## Appendix B

Table B1  
Stimuli Used for the Different Response in Experiment 2

Target	TL-Allog	TL+Allog	SL-Allog	SL+Allog	Baseline	Reference
يخدلون yaXLuDuuna	يلخدون yaLXuDuuna	يخدلون yaXDuLuuna	يظلدون yaZBuDuuna	يخذنون yaX* uKuuna	نلشدهم naLDa\$uhum	يبتنعون yaNtaFiEuuna
يسهلان yaSaH~iLaani	ياهاسا~iLaani yaHaS~iLaani	يوسال~iHaani yuSaL~iHaani	يوسال~iLaani yuJaD~iLaani	يوسال~i*aani yuSaD~i*aani	احضكتي aHDaKaTii	أغلبهم aGLuBuhum
يظهرون yuZHiRuuna	يظهرون yuZHiRuuna	يظرون yuZriHuuna	يظشرون yuSaRiRuuna	يظربون yuZziBuuna	تستذوق tasta*NiQu	أهريوا uHRuBuu
يتجمهرون yataJaMhaRuuna	يتجمهرون yataMaJhaRuuna	يتجرهمون yataJaRhaMuuna	يتقبرهون yataQaBhaRuuna uuna	يتجصهون yataJaShaKuuna	تستاغون tasta<GiFuuna	تنبطحان tanBaTiHaani
يسيطرون yuSaYtiRuuna	بيسطرون yuYaStiRuuna	يسرطيون yuSaRtiYuuna	يلظرون yuLaVtiRuuna	يصبكطهون yuSaKtiHuuna	تتقاجدن nataQaJDaNu	تظفرون aZEumu
يصهرون yaShaRuuna	يحصرون yaHSaRuuna	يصرهون yaSRaHuuna	يظشرون ya\$ZaRuuna	يصبكون yaSbaKuuna	تطاشعنه iKEaaSun	أضحكتي aDHaKaniii
يعنصرونه yuEaNsiRuunahu	يعنصرونه yuNaEsiRuunahuahu	يعرصونه yuEaRsiNuunahuah	يعنصرونه yuGaTsiRuunahuahu	يغصظونه yuEaJsiZuunahuunahu	تغصظونه tuXaLbiZaanihi	تظفرون tuTFi > uuna
ينتزها yaNVuRuhaa	ينتزها yaVNuRuhaa	ينتزها yaNRuVuhaa	ينتزها yaDQRuhaa	ينتزها yaNSuTuhaa	انحضخت inHaDaXat	تتظفلان tataTaFaLaani
يتفزون taBaHRaJat	يتلفزون taHaBRaJat	يتزفلون taBaRHajAt	يتفزون taXaFRaJat	يترفجون taBaHFajAt	يخلصفها yuXaLsiFuhaa	يؤمونه yu<aM~iNuunah
يتلمذون yuTaLfiZuuna	يتلمذون yuTaLfiZuuna	يتتلمذون yuTaZfiLuuna	ييجمذون yuTaZfiZuuna	ييترفجون yuTaRfiJuuna	أبرفهم uHaFNiJuhu	تتظفرون tuBayYiNuuna
يجمذون yataTaLma* uuna	يجمذون yataLaTma* unana	يجمذون yataTa*MaLuuna	يجمذون yataBaJMa* uuna	ييترمقون yataTaRmaQuuna	أحنجه uHaRDiQuhum	أحركك uHaR~iKuka
يبحشرج yuJaLmiDuuna	يبحشرج yuJaLmiDuuna	يبحشرج yuJaDmiLuuna	يبحشرج yuHaQmiDuuna	يبحشرج yuJaRmiQuuna	يبحشرج tuBADDi\$aaani	يبلبها yaLbaSuha
يحمذون yataHa\$RaJu	يحمذون yata\$HRaJu	يحمذون yataHRa\$aju	يحمذون yataSaVRaJu	يحمذون yaTaHaTLaJu	تتكلمسان tuNaKLiSaani	انقضت inQaBaDat
تختفلان yuHaMDiLuuna	تختفلان yuMaHDiLuuna	تختفلان yuHaDMiLuuna	تختفلان yuHaSDiLuuna	تختفلان yuHaSTiLuuna	أطغصظون uTaF\$BiBuHum	أصرخوا iSRaXuu
تطغرس taXtaLiFaani	تطغرس taXtaLiFaani	تطغرس taXtaLiFaani	تطغرس taXtaLiFaani	تطغرس taXtaLiFaani	استغشغت istaQ\$Gat	يولفها yuAL~iFuhaa
يشتغلان taGaTRaSat	يشتغلان taTaGRaSat	يشتغلان taGaTRaSat	يشتغلان taTaGRaSat	يشتغلان taGaFLaSat	يبتكشطن yataKa\$TaNu	استأثرت istaVaRatu
يبتسرون ya\$taGiLaani	يبتسرون yaGta\$Laani	يبتسرون ya\$taLiGaani	يبتسرون yaBtaLiLaani	يبتسرون ya\$taDiRaani	يبتسرون istaZNaJat	يبتسرون iQtaTalu
يضمحان yaSTuRuuna	يضمحان yaTSuRuuna	يضمحان yaSRuTuuna	يضمحان yaHDuRuuna	يضمحان yaSDuKuuna	يضمحان a\$LaHahaa	يضمحان yuSaD~iQuhu
يتعجرفون yaDMahiLaani	يتعجرفون yaMDahiLaani	يتعجرفون yaDLahiMaani i	يتعجرفون yaSBahiLaani	يتعجرفون yaDDahiBaani	يتعجرفون tuBaSEiDuuna	أثنتهاها tataLaH~aFaani
يتعجرفون yataEaJRaFuuna	يتعجرفون yataJaERaFuuna	يتعجرفون yataEaRJaFuuna	يتعجرفون yataSaHRaFuuna	يتعجرفون yataEaQLaFuuna	يبتعجرفون uKaSNiFuhaa	تتغسلون aVbaTnaahaa
تصلحان yataEaFRataani	تصلحان yataFaERataani	تصلحان yataEaRFataani	تصلحان yataNaDRataani	تصلحان yataEaLJataani	تصلحان nuQaJLiBuhum	تصلحان taGtaSiLuuna
يفرسون tuSLiHaani	يفرسون tuSLiHaani	يفرسون tuSHiLaani	يفرسون tuJkiHaani	يفرسون tuSDiZaani	أرتخي iRtaXiBii	أعزني aEJaZanii
يقشعرون yuFaHRiSuuna	يقشعرون yuHaFRiSuuna	يقشعرون yuFaRHiSuuna	يقشعرون yuQa\$RiSuuna	يقشعرون yuFaSTiSuuna	أجدتقتا iJtaDaQataa	أنفخها aSMaEnaahu
يقنبلان yaQ\$aeiR~uuna	يقنبلان yaQ\$aeiR~uuna	يقنبلان yaQ\$aeiR~uuna	يقنبلان yaFSaciR~uuna	يقنبلان yaQDaEiT~uunana	يقنبلان iBtaXaTu	أضعت aNFuXuhaa
تقنطرون yuQaNBiLaani	تقنطرون yuNaQBiLaani	تقنطرون yuQaLbiNaani	تقنطرون yuFaTbiLaani	تقنطرون yuQaDbi*aani	أحزجدوا iHJaZiDuu	أختلسوا iXtaLaSuu
يتشقلبان tuQaNTiRuuna	يتشقلبان tuNaQTiRuuna	يتشقلبان tuQarTiNuuna	يتشقلبان uFaBtiRuuna	يتشقلبان tuQaHtiJuuna	أفكرحما iBVaTiSuu	تزلحلت aJHaSat
يكفرون yata\$QLaBaani	يكفرون yata\$QLaBaani	يكفرون yata\$QBaLaani	يكفرون yata\$HSaBaani	يكفرون yata\$QDaRaani	أفكرحما uKaFXiRuhumaa	انتصرون taZaHLaqat
يهيكلان yaKFaHiR~uuna	يهيكلان yaKFaHiR~uuna	يهيكلان yaKRahiF~uuna	يهيكلان yaTJahiR~uuna	يهيكلان yaKDahiM~uuna	أفكرحما tatJaLbaDuuna	يصلطعون iNtaSaRna
يهاكليLaani	يهاكليLaani	يهاكليYaani	يهاكليLaani	يهاكليZaani	أفكرحما a\$*aMaTaahu	يهاكليEna

(Appendices continue)



Table B1 (continued)

Target	TL-Allog	TL+Allog	SL-Allog	SL+Allog	Baseline	Reference
بيهدله yuBaHDiLuhu أعنيها	بيهدله yuHaBDiLuhu أعنيها	بيهدله yuBaDHiLuuna أعنيها	يقتهله yuQaVDiLuhu أعظصها	بيجقله yuBaJQiLuhu أذننها	أغسفقه uGaSFiQuhu ينطكبه	يتشاجرون yata\$aaJaRna انفضوا
uEaB~i<uhaa أعنيها	uEa<~iBuhaa أعنيها	uBaE~i<uhaa أعنيها	uEaZ~iSuhaa أعصنها	uDaZ~<ihaa > uhaa أرذنها	yanTaKiBuhu تذظفان	iNFaDuu ارتبطت
aEJuNuhaa أظلمت	aENuJuhaa أظلمت	aJEUuNuhaa أظلمت	aESuVuhaa أظلمت	aR*uNuhaa أظلمت	tuDaZ~iFaani انتقست	iRtaBaTat يتحيزون
aZLaMat أسكها	aZMaLat أسكها	aLZaMat أسكها	aZTaQat أسجها	aD*aMat أزجها	tanQaSiSu يحنصون	yataHaYyaZuuna يتواعدون
aSLuKuhaa النيها	aSKuLuhaa النيها	aLSuKuhaa النيها	aSJuxuhaa النيها	aZJuKuhaa أظنها	yaHNiSuuna ياسجهم	yataWaaEaDuuna اكتشفوا
uLaY~iNuha أعشيم	uYaL~iNuha أعشيم	uYaL~iNuha أعشيم	uLaZ~iBuha أعكهم	uTa*~iNuha أز دشيم	Ya<SuJuhum تيلكان	iKta\$afuu امتلكت
uEaT~i\$uhum التهوا	uEaT~i\$uhum التهوا	uTaE~i\$uhum التهوا	uEaK~i<uhumm الطغوا	uZaD~i\$uhum ادرثوا	tuYaKLinu نجرظه	iMtaLaKat تجوان
iLHaVuu أعكسها	iLVaHuu أعكسها	iHLaVuu أعكسها	iLTaGuu أعظها	iDRaVuu أندسها	naZuZuhu يتلفظن	taNJuaWani يملته
aEKuSuhaa المعهم	aESuKuhaa المعهم	aKEuSuhaa المعهم	aEZuQuhaa الظجهم	a*Dusuhaa أصعهم	yataLaF~aTna نجتغظه	yaMLa<nahu البثوا
uLaMiEuhum أعظسها	uLaEiMuhum أعظسها	uMaLiEuhum أعظسها	uLaZiJuhum أعظسها	uDaSiEuhum أذسها	naJaGiTuhu تشتاؤون	iLbaVuu أعدكم
uGaT~iSuhaa أغمسه	uGas~iTuhaa أغمسه	uTaG~iSuhaa أغمسه	uGaf~iEuhaa أعظسه	uDa*~iSuhaa أندسه	ta\$<aVuuna ننذره	aEiDuKum يهبطون
uGAM~iSuhu أجسنتها	uGas~iMuhu أجسنتها	uMaG~iSuhu أجسنتها	uGaj~iTuhu أجكتها	uVaD~iSuhu أدقستها	naD*uZuhu نقذهم	yaHbiTuuna تسبون
aJLaStuhaa أخلفها	aJLaTuhaa أخلفها	aJJaStuhaa أخلفها	aJKaEtuhaa أخبضها	aDQaStuhaa أبدقها	naQFu*Uhum تدذجون	taHSiBuuna تستنبطون
aXLuQuhaa أعظشت	aXQuLuhaa أعظشت	aLXuQuhaa أعظشت	aXBuDuhaa أعظشت	aBDuQuhaa أحزشت	taD*uJuuna تهدأقت	tastaNBiTuuna تخلصون
aGTa\$at أعتمت	aG\$at أعتمت	aTGa\$at أعتمت	aGVaF أعنت	aHZa\$at أز نمت	taHaa*Qat ينثون	tuXLiSuuna أرسمها
aETaMat أعجموا	aEMaTat أعجموا	aTEaMat أعجموا	aEKaNat أعجموا	aZ*aMat أعجموا	yaNVuXuuna تلاظصت	arSuMuHaa أقدمهن
uEJiMuu أعضلهم	uEMiJuu أعضلهم	uEiMuu أعضلهم	uELiZuu أعضصهم	u*GiMuu أزرلهم	taLaaZaSat يبحدون	uQaDdiMuhunna أصدروا
aEDuLuhum أعظسني	aELuDuhum أعظسني	aDEuLuhum أعظسني	aESuSuhum أعصني	aZRuLuhum أزسنني	yuBHiDuuna يخطها	aSDaRuu أمنها
aETaSanii أبغضت	aESaTanii أبغضت	aTEaSanii أبغضت	aEaSanii أبجت	aETaSanii أقرضت	yakXuTuhaa نسنشه	uNaM~iiaha أواقه
aBGaDat أسلخها	aBDaGat أسلخها	aGBaDat أسلخها	aBVaJat أسبثها	aQZaDat أبدخها	nuS<i\$uhu تجطحن	uWaaFiQuhu تلتظون
aSLaXuhaa أنمنا	aSXaLuhaa أنمنا	aLSaXuhaa أنمنا	aSLaXuhaa انجنا	aBLaXuhaa اندخنا	taKJuTiina ييشدون	tuLaT~iXuuna أبوا
aNEaMna أصلبها	aNMaEna أصلبها	aENaMna أصلبها	aNXaJna أصجها	aDXaMna أزديها	yaB\$uDuuna يتجنون	aBaWaa تسكبنا
aSLuBuhaa أعقمها	aSBuLuhaa أعقمها	aLSuBuhaa أعقمها	aSJQuhaa أعجمها	aSLuBuhaa أبدقمها	yataJaNwaQu يصدرجان	tanSaKiBaani أرعاها
uEaLQiMuhaa أطبعا	uEaQLiMuhaa أطبعا	uLaEQiMuhaa أطبعا	uEaJBiMuhaa أطبعا	uBa*QiMuhaa أثرعها	yaSaBRiJaani نجافته	aREaahaa أحقها
aTBaEuhaa أثجوا	aTEaBuhaa أثجوا	aBTaEuhaa أثجوا	aTJaMuhaa أثكوا	aVRaEuhaa أحذوا	nuJaaFiTuhu تحدزين	uHaQ~iQuha اندوا
aVLaJuu أعفلها	aVJaLuu أعفلها	aLVaJuu أعفلها	aVTaKuu أعغها	AH*aJuu أرزفها	taHDuZiina نقالتهم	aDNuu أجهضت
aELuFuhaa ارتنت	aEFuLuhaa ارتنت	aLEuFuhaa أهترنت	aEMuGuhaa ارتضت	aRZuFuhaa أقتشنت	nuQaaLiVuhum يلاديه	taKta<iBaani أجهضت
iRtaHaNat أفعلها	iRtaNaHat أفعلها	iHtaRaNat أفعلها	iRtaDa\$at أفجها	iQta\$aNat أذلها	yaLaaDiBuhu نظاقيه	aJHaDat أكفهم
aFEaLuhaa أعظمهم	aFLaEuhaa أعظمهم	aEfaLuhaa أعظمهم	aFkaJuhaa أعضمهم	aDZaluhaa أزقمهم	nuZaaQiBuhu تمظبوا	uKaL~iFuhum أوجدوا
uEaZiMuhum أغلظت	uEaMiZuhum أغلظت	uZaEiMuhum أغلظت	uEaFiDuhum أغلظت	aZQuMuhum أغلظت	tuMziBuu تسحتت	aWJaDuu أنهلوا
aGLaZat	aGZaLat	aLgaZat	aGSaHat	aWBaZat	taHaS~aVat	iNHaLuu

Note. In the appendices, the asterisk (\*) represents the Arabic letter ذ and the tilde (~) represents gemination.

(Appendices continue)

## Appendix C

Table C1  
*Stimuli Used for the Same Response in Experiment 3*

Target	TL-Allog	TL+Allog	SL-Allog	SL+Allog	Baseline
تخذان tuNXi*aani	تخذان tuXaNi*aani	تنخذان tuNa*~iXaani	تجدقان tuJaQi*aani	تنطشان tuNaZiSaani	استنقل istaVNaLa
ينبحزون yanBaHiZuuna	ينبحزون yanHaBiZuuna	ينبحزون yanBaZiHuuna	ينبلزون yanTaLiZuuna	ينبکصون yanBaKiSuuna	تضاصموا taDaaSaMuu
يفقدان yuf\$SiDaani	يفقدان yuf\$FiDaani	يفقدان yufDi\$Saani	يفقدان yuQNiDaani	يفقدان yuF<iSaani	انكرفتا inKaRaFataa
ييمزون yaBMuZuuna	ييمزون yaMBuZuuna	ييمزون yaBZuMuuna	يلخزون yaLXuZuuna	بييجون yaBDuJuuna	تجامن taJaaMaKna
تغذان tuGLi*aani	تغذان tuLaGi*aani	تغذان tuG*iLaani	تغذان tuB<i*aani	تغذان tuGTiHaani	يكهبان yaKbHaani
تنكشون tan\$KaKiZna	تنكشون tanKa\$SiZna	تنكشون tan\$aZiKna	تنكشون tan<aHiZna	تنكشون tan\$aZiLna	تغامن taGaaMaHna
ينقبزان yanQaBiZaani	ينقبزان yanBaQiZaani	ينقبزان yanQaZiBaani	يجظزان yanJaTiZaani	ينقفمان yanQaFiMaani	تجاجوا taMaaJaKuu
يکيزون yaKBuZuuna	يکيزون yaBKuZuuna	يکيزون yaKZuBuuna	يکيزون yaTZuZuuna	يکيفون yaKNuGuuna	استمغ istaMGaQa
تلمران taLMuRaani	تلمران taMLuRaani	تلمران taLRuMaani	تلمران taHNuRaani	تلجفان taLJuFaani	تماسن taMaaEaSna
يفظزون yaQZuZuuna	يفظزون yaZQuZuuna	يفظزون yaZZuQuuna	يفظزون yaFTuZuuna	يفظزون yaQB\$uuna	نستكج nastaKLiJu
يصبذان yaSBu*aani	يصبذان yaBSu*aani	يصبذان yaS*uBaani	يفقدان ya<Qi*aani	يصبجان yaSTuJaani	تامعرا taMaaEaRaa
تشفدان ta\$FuDaani	تشفدان taF\$uDaani	تشفدان ta\$DuFaani	تشفدان taTVuDaani	تشفقان ta\$QuMaani	استنخش istaNXa\$a
تطبذان taTBi*na	تطبذان taBTi*na	تطبذان taT*iBna	تجدذن tajHi*na	تطفخن taTFiXna	يکاعش yuKaaEi\$u
يلظرون yaLZiRuuna	يلظرون yaZLiRuuna	يلظرون yaLRiZuuna	يلسرون yaS\$Ruuna	يلفون yaLQiEuuna	تنامن TaNaMaKna
يعدان yaVEaDaani	يعدان yaEaDaani	يعدان yaVDeaani	يصبذان yaSDaDaani	يچجان yaVJaKaani	انتعظا iNtaGaZaa
يقلزون yaQLiZuuna	يقلزون yaLQIZuuna	يقلزون yaQZILuuna	يفظزون yaEFIZuuna	يفظزون yaQTIVuuna	استمطمش istaZMa\$a
تظفوان taZGuWaani	تظفوان taGZuWaani	تظفوان taZWuGaani	تنظوان ta<VuWaani	تظکلان taZKuLaani	تکاخمن taKaaXaMna
يسلزون yaSLu*uuna	يسلزون yaLSu*uuna	يسلزون yaS*uLuuna	يبيزون yaHYu*uuna	يسبسون yaSBU\$uuna	انظمعا iZtaMaEa
تھکرون taHKiRuuna	تھکرون taKHiRuuna	تھکرون taHRIKuuna	تھکرون ta<HiRuuna	تھيقون taHBiQuuna	تثاظمتم taVaaZaMat
انکھزت inKaHaZat	انکھزت inHaKaZat	انکھزت inKaZaHat	انکھزت inTaEaZat	انکھزت inKaLaDat	يتخاقم yataXaaQaMu
انعمدا inEaMa*aa	انعمدا inMaEa*aa	انعمدا inEa*aMaa	انعمدا inGaTa*aa	انعمشا inEaSa\$aa	تواثلت taWaa\$LaLat
يلطران yaLTiRaani	يلطران yaTLiRaani	يلطران yaLRiTaani	يصبضان yaSDiRaani	يلطشان yaLZi\$Saani	استمجت iStaMaJat
انظلا inTaLaZaa	انظلا inLaTaZaa	انظلا inTaZaLaa	انظلا infaGaZaa	انظقا inTaQaFaa	هائشعوا Haa\$EuEu
انقرون inVaQaRna	انقرون inQaVaRna	انقرون inVaRaQna	انقرون inXaJaRna	انثين inVaBaVna	تصامفا taSaaFaMaa
يمتشدان yaMtaSiDaani	يمتشدان ya\$taMiDaani	يمتشدان yaMtaDi\$Saani	يمتشدان yaStaNiDaani	يمتخدان yaMtaXiJaani	تقافسوا taQaaFaSuu
ييمزون yaTMuZuuna	ييمزون yaMTuZuuna	ييمزون yaTZuMuuna	ييلخزون yaTXuZuuna	ييلخزون ya<TaSuuna	تقاطن taQaaTaVna
استكطدت istaKTaDat	استكطدت istaTKaDat	استكطدت istaKDaTat	استكطدت istaBDaDat	استكطقت istaKNaQat	اعتقسنا iEtaQaSataa
انشهزتا in\$aHaZataa	انشهزتا inHa\$aZataa	انشهزتا in\$aZaHataa	انشهزتا inKaLaZataa	انشخفتا in\$aXaFataa	تواغمو taWaaGaMuu

(Appendices continue)

Table C1 (continued)

Target	TL-Allog	TL+Allog	SL-Allog	SL+Allog	Baseline
استخبدين istaXBaDna	استخبدين istaBXaDna	استخبدين istaXDbaDna	استصبدين istaSQaDna	استخلكن istaXLaKna	انطذروا inTaDaZuu
ينبجندان yanVaJiDaani	ينبجندان yanJaViDaani	ينبجندان yanVaDiJaani	ينبظندان yanZaTiDaani	ينبشان yanVaBiNaani	انفقتا inFaQaLataa
أعجفنا aEJaQnaa	أعجفنا aEQaJnaa	أعجفنا aEJaQnaa	أعظفنا aEBaZnaa	أذرفنا aDZaQnaa	ينطحون yaVaTaHuuna
أغصوا aGLaSuuu	أغصوا aGSaLuuu	أغصوا aLGaSuuu	أغصوا aG<aSuuu	أغصوا aB*aSuuu	يدخكان yaDXuKaani
أغمثنا aGMaVataa	أغمثنا aGVaMataa	أغمثنا aMGA Vataa	أغمثنا aGfA Kataa	أزرفنا aZRa Vataa	ينفهاط yatHaFaTu
أعظن aEBaZna	أعظن aEzaBna	أعظن aBEaZna	أعظن aENa\$na	أزرفن aZRazna	جاوخت JaaWaXat
أكففت aKGaFat	أكففت aKfaGat	أكففت aGKaFat	أكففت aKSaTat	أرطفت aRTaFat	تزاق tuZaaXiQu
أعطنا aELaZataa	أعطنا aEzaLataa	أعطنا aLEaZataa	أعطنا aENaSataa	أدظنتا AD*aZataa	تاجرت taKaWaJuu
أغصوا aGSaTuuu	أغصوا aGTaSuuu	أغصوا aSGaTuuu	أغصوا aG\$Zuu	أزظوا aZDaTuuu	استمخ istaMXaJa
أعظنا aSEaZataa	أعظنا aSZaEataa	أعظنا aESA Zataa	أعظنا aSGaTataa	أدظنتا aDQaZataa	تجاغرت taJaaGaRat
أمظوا aMGaZuu	أمظوا aMzaGuu	أمظوا aMzaZuu	أمجصوا aMJaSuuu	أنظوا a*ZaZuu	يخامهن yuXaaMiHna
أغشا aTGa\$aa	أغشا aT\$aa	أغشا aGTa\$aa	أغشا aTeaVaa	أدزشا aDZa\$aa	تراغث taRaaGaVat
أكلوا aKEaLuu	أكلوا aKLaEuu	أكلوا aEKaLuu	أكلوا aKgaJuu	أدولوا AD*aLuu	استفقع istaFQaGa
اعتضوا iEtaQaDuu	اعتضوا iEtaDaQuu	اعتضوا iQtaEaDuu	اعتضوا iEtaVaMuuu	ارتضوا iRtaDaDuu	استغركت istaGRaKat
أعلوا aELaVuu	أعلوا aEVaLuu	أعلوا aLEaVuu	أعلوا aEBaDuu	أزذوا aZDaVuu	يطامخن yaTaaMiXna
أصغفنا aSGaFataa	أصغفنا aSFaGataa	أصغفنا aG\$SaFataa	أصغفنا aSJaTataa	أزرفنا aRZaFataa	يتشاكخ yata\$aaKaXu
أغتمكوا iGtaMaKuu	أغتمكوا iGtaKaMuuu	أغتمكوا iMtaGaKuu	أغتمكوا iGtaNaBuuu	أذنتكوا i*taDaKuu	استهفلت istaHLaFat
أشغستا a\$SaGataa	أشغستا a\$SaGataa	أشغستا aG\$SaGataa	أشغستا a\$FaKataa	أذدستا a*DaSataa	تتعاطش tataEaZa\$u
أعقوا aEQaVuu	أعقوا aEvaQuu	أعقوا aQeaVuu	أعقوا aEJaXu	أزرفوا aRZaVuu	تكارزن taKaaZaRna
أنفقتا aNgaFataa	أنفقتا aNFaGataa	أنفقتا aNGaFataa	أنفقتا aNGaFataa	أذرفنا aDZaFataa	تماجت taMaHaJat
أعضوا aEFaDuu	أعضوا aEDaFu	أعضوا aFEaDuu	أعضوا aEQaZuu	أذصوا aDZaDuu	استغفر istaGVaRa
أنغست aNgaSat	أنغست aNSaGat	أنغست aNGaSat	أنغست aNVaHat	أذدست AD*aSat	ضامجت DaaMaJat
أظصتا aZEaSataa	أظصتا aZSaEataa	أظصتا aEzaSataa	أظصتا aZTaGataa	أذصتا aDZaSataa	استكفم IstaFKaMa
أبغوا aBGaMuu	أبغوا aBmaGuu	أبغوا aGBaMuu	أبغوا aBvaJuu	أذموا AD*aMuu	يتالس yataNaaLuSu
أشغفنا a\$GaNataa	أشغفنا a\$NaGataa	أشغفنا aG\$aNataa	أشغفنا a\$JaFataa	أذدنا AZ*aNataa	يتفاقت yataFaaQatu
أثسعووا iVtaEaSuuu	أثسعووا iVtaSaEuuu	أثسعووا iEtavaSuuu	أثسعووا iVta<aNuuu	أذدقوا iZdaQaSuuu	تتازدوا taNaaZaDuu
أمغشوا aMGaSuuu	أمغشوا aM\$GaSuuu	أمغشوا aGmaSuuu	أمغشوا aMEaTuuu	أزرفوا aRZaSuuu	يخالزن yuXaaLiZna
أعكتنا aEKaVnaa	أعكتنا aEvaKnaa	أعكتنا aKEaVnaa	أعكتنا aE<aDnaa	أذدثنا a*DaVnaa	انهفقت iNHaFaQna
أفتوا aEFaTuuu	أفتوا aETaFu	أفتوا aFEaTu	أفتوا aESaTu	أذدوا aRDaTu	تماكلت taMaaKaLat
أجفن aJGaFnaa	أجفن aJfaGnaa	أجفن aGJaFnaa	أجفن aJEa\$naa	أزرفن aZDaFnaa	يفاسع yuFaaSiEu
أطعوا aTEaQuuu	أطعوا aTqaEu	أطعوا aETaQuuu	أطعوا aTgaBu	أذدقوا AD*aQuuu	استهشج istaH\$Ja
أعقتنا aGTaFataa	أعقتنا aGfaTataa	أعقتنا aTgaFataa	أعقتنا aGSaLataa	أدققتنا aDQaFataa	تنهائط tataHaaNaTu

Note. In the appendices, the asterisk (\*) represents the Arabic letter ذ and the tilde (~) represents gemination.

(Appendices continue)

Table C2  
 Stimuli Used for the Different Response in Experiment 3

Target	TL-Allog	TL+Allog	SL-Allog	SL+Allog	Baseline	reference
انصدكتا	انكصدتا	انصدكتا	انعددتا	انصدجتا	يجابطون	تتماجخ
inSaKaDataa	inKaSaDataa	inSaDaKataa	inEa\$aDataa	inSaJaFataa	yaJaaBiTuuna	tataMaaJaXu
استعكوتا	استعكوتا	استعكوتا	استعكوتا	استعظجتا	يداغزان	تتجابض
istaEKaWataa	istaKEaWataa	istaEWaKataa	istaXVaWataa	istaEJaJataa	yuDaaGiZaani	tataJaaBaDu
انغزبوا	انغزبوا	انغزبوا	انغزبوا	انغظكروا	يتغاسفن	تطافخن
inFaBaZuu	inBaFaZuu	inFaZaBuu	inHaQaZuu	inFaTaKuu	yataGaaSaFna	taTaaQaXna
ينقجران	ينقجران	ينقجران	ينقجران	ينققتان	استمطغا	استعقش
yanQaJiRaani	yanJaQiRaani	yanQaRiJaani	yanXaKiRaani	yanQaFiTaani	istaMTaGaa	istaFQa\$a
تسبون	تسبون	تسبون	تسبون	تسطفون	انشجفا	استهفز
tuSbiDuuna	tuSbiDuuna	tuSDiBuuna	tuN<iDuuna	tuSBTiFuuna	in\$aJaQaa	istaFHaZa
تكهوان	تكهوان	تكهوان	تيخوان	تكصمان	عافلوا	تتغاسط
taKHuWaani	taKHuWaani	taKWuHaani	taBXuWaani	taKSuMaani	EaaJaLuu	tataJaaSaTu
انغذوا	انغذوا	انغذوا	انصدوا	انغظوا	يتثابشن	تتساكتا
inGaFaDuu	inFaGaDuu	inGaDaFuu	inSaVaDuu	inGaTaZuu	yataVaBa\$na	ta\$aKaVataa
استحذكت	استحذكت	استحذكت	استحذكت	استحصقت	تغافطوا	تتغاقطوا
istaHKa*at	istaHKa*at	istaH*aKat	istaNJa*at	istaH\$aQat	taGaaFaTu	taJaaQaTu
ينطدان	ينطدان	ينطدان	يقضدان	ينظغان	انغوسا	اجتظكت
yaNTuDaani	yaNTuDaani	yaNDuTaani	yaQDuDaani	yaNZuGaani	inGawaSaa	iJtaZaKat
انتقزوا	انتقزوا	انتقزوا	انضبروا	انثشما	يتواغر	استفخد
inVaQaZuu	inQaVaZuu	inVaZaQuu	inDaBaZuu	inVa\$aMuu	yataWaGaRna	istaFDaXa
انحشرا	انحشرا	انحشرا	انلشا	انحظا	مازغوا	استخف
inHaSaZaa	inSaHaZaa	inHaZa\$a	inBaLaZaa	inHaQaTaa	MaZaGuu	istaXMaFa
تتمزان	تتمزان	تنزمان	تنظزان	تنظخان	تواجطن	تتغافتا
taNMuZaani	taNMuZaani	taNZuMaani	taTZuZaani	taNTuXaani	taWaaJaTna	taHaaFaJataa
تظكران	تظكران	تظكران	تظكران	تظكران	يجطلون	استوجض
taKaTuZaani	taTaKuZaani	taKaZuTaani	taHaZuZaani	taKaJuHaani	yaJTiLuuna	istaWJaSa
تغذون	تغذون	تغذون	تغذون	تغمعون	اضجدي	تغافطا
taGViDuuna	taGViDuuna	taGDiVuuna	taSXiDuuna	taGMeEuuna	aDJaDanii	taHaaVaHaa
بيتهدون	بيتهدون	بيتهدون	بيتهدون	بيتهغون	تلاكان	استعقش
yaHtaTiDuuna	yaTataHiDuuna	yaHataDiTuuna	yaHtaBiDuuna	yaHtaFiGuuna	tuLaaKiGaani	istaF\$aTa
نهبها	نهبها	نهبها	نهبها	نهبها	يكعدون	يسخمن
naHBuZuha	naHBuZuha	naHZuBuha	naHJuZuha	nuH<iTuhaa	yaKEduDuuna	yasXaMiTna
تجدون	تجدون	تجدون	تظفون	تجلون	العكها	يغافجن
tuJGiDuuna	tuJGiDuuna	tuJDiGuuna	tuZFiDuuna	tuJNiLuuna	aLEuKuhaa	yuFaaJiQna
يكتون	يكتون	يكتون	يغعون	يكتون	تغيدان	يطشون
yaKVuWuuna	yaKVuWuuna	yaKWuVuuna	yaKEuWuuna	yaKFuQuuna	taGBU*aani	yaT\$aEuuna
استلخرهم	استلخرهم	استلخرهم	استلخرهم	استلخرهم	يستعظان	تتتخان
astaHLiRuhum	astaHLiRuhum	astaHLiRuhum	astaS\$Ruhum	astaH\$Xuhum	yastaNEiZaani	tataVaHaNu
نمشها	نمشها	نمشها	نجحها	نمظها	اطعنا	انثشوا
naM\$uZuha	naM\$uZuha	naM\$uSuha	naJHuZuha	naMZuTuha	aT\$a\$unaa	aV\$aSuu
تتمزون	تتمزون	تتمزون	تظظون	تتقظون	اغشعهم	انخيك
tuVMiZuuna	tuMViZuuna	tuVZiMuuna	tuZTiZuuna	tuVQiDuuna	aG\$aEuHum	inXaBaKat
يعذون	يعذون	يعذون	يقذون	يعصون	نغصها	تتالزن
yaETa*uuna	yaTEa*uuna	yaE*aTuuna	yaQ<a*uuna	yaE\$aSuuna	nuG<iSuhaa	taHaaLaZna
استسده	استسده	استسده	استسده	استسكه	يعتمصون	اجتمقتا
astaSHi*uhu	astaHSi*uhu	astaS*iHuhu	astaTKi*uhu	astaS<iKuhu	yaEtaMiSuuna	iJtaMaQataa
نجبها	نجبها	نجبها	نغزها	نجنثها	اكتظها	استهالج
nuJBiZuhaa	nuJBiZuhaa	nuJZiBuhaa	nuGNiZuhaa	nuJ<iVuhaa	aKZuFuhaa	istaHLaJa
تصكرنا	تصكرنا	تصكرنا	تصكرنا	تصبضنا	نجظها	اصدكتا
taSKuRunaa	taKSuRunaa	taSRuKunaa	taH\$uRunaa	taSBuDunaa	naJGuZuha	aSHaDataa
يغصون	يغصون	يغصون	يقظون	يغظون	تصصنان	هالدت
yaGSiDuuna	yaSGiDuuna	yaGDiSuuna	yaVQiDuuna	yaG<iFuuna	taSDuNaani	HaaLaDat
ننكدهم	ننكدهم	ننكدهم	ننكدهم	ننثهم	يغظون	يستلخم
naTKuDuhum	naKTuDuhum	naTDuKuhum	naL<aDuhum	naTBuVuhum	yaG<iDuuna	yastaXLiMu
تفدون	تفدون	تفدون	تخندون	تفنون	اهظها	استطيك
tuFLiDuuna	tuFLiDuuna	tuFDiLuuna	tuX<iDuuna	tuFniQuuna	uHaYiTuhaa	istaTbaKa
استقزهم	استقزهم	استقزهم	استمزمهم	استقشهم	ييشونها	تتاشخا
astaQJiZuhum	astaQiZuhum	astaQZiJuhum	astaMHiZuhum	astaQ<i\$uhum	yuYa\$uNahaa	taMaaSaXaa
يهدكان	يهدكان	يهدكان	يهدكان	يهدخان	اخشها	يتصاخط
yuHKiDaaNi	yuKHiDaaNi	yuHDiKaaNi	yuJ\$iDaaNi	yuHniXaaNi	aXLa\$tuhaa	yataZaaXaTu

(Appendices continue)

Table C2 (continued)

Target	TL-Allog	TL+Allog	SL-Allog	SL+Allog	Baseline	reference
أغظوا	أغظوا	أغظوا	أغظوا	أذلفوا	تألجنا	نتأخجم
aGZaFuu	aGFaZuu	aZGaFuu	aGBaVuu	a*LaFuu	taaLaJaTaa	nuTaaXiJuhum
اعتصوا	اعتصوا	التعصوا	اعتصوا	ازدجصوا	تتأفوا	انفرتت
iEtaLaSuu	iEtaSaLuu	iLtaEaSuu	iEtaBa\$uu	iZtaJaSuu	taNaaFaJuu	inFaRaTat
أمعجتا	أمعجتا	أمعجتا	أملظتا	أرنجتا	استمكح	انفشكن
aMEaJataa	aMJaEataa	aEMaJataa	aMLaZataa	aRNaJataa	istaMKaHa	inFaKa\$na
أغفوا	أغفوا	أغفوا	أغفوا	أظفوا	تقامت	استككت
aGFaJuu	aGJaFuu	aFGaJuu	aGAAuu	aDZaJuu	taQaaMaVat	istaVKaTa
أفطوا	أفطوا	أفطوا	أفجوا	أنمطوا	يتخامت	ماخسوا
aFGaTuu	aFTaGuu	aGFaTuu	aFJaHuu	a*MaTuu	yataXaaMaVu	MaaXa\$uu
اعستوا	اعستوا	اسعتوا	اعطصوا	ازحنوا	يفاقن	ينشون
iESaTuu	iETaSauu	iEaTuu	iETaDuu	iZHaTuu	yuQaFiKna	yaNVi\$uuna
العضتا	العضتا	أعضتا	الغثتا	أبرصتا	انطمعا	تتخاكن
aLEaDataa	aLdaEataa	aELaDataa	aLgaVataa	aBRaDataa	inTaMaGaa	tataXaaKa\$u
أعتوا	أعتوا	أعتوا	أعبوا	أشذوا	تجامقا	يشاكظن
aEVaTuu	aETaVuu	aVEaTuu	aEBaXuu	a\$*aTuu	taJaaMaQaa	yuSaaKiTna
أعجتا	أعجتا	أعجتا	أعظتا	أذجتا	استثما	تصابتن
aETaJataa	aEJaTataa	aTEaJataa	aEzaGataa	aDXaJataa	istaVMaYaa	taSaaBaTna
أفجوا	أفجوا	أفجوا	أقبوا	أزرجوا	تصامفن	تكامهن
aQEAjuu	aQJaEuu	aEQaJuu	aQEAjuu	aZRaJuu	taSaaMaQna	taKaaMaHna
أغفت	أغفت	أغفت	أغصت	أنزت	صاكنظن	يشمك
aGFaQat	aGQaFat	aFGaQat	aGSaJat	a*ZaQat	DaaKaTna	yasTamSiKu
أغشنا	أغشنا	أغشنا	أغشنا	أبدشنا	تشافنا	يخاوطن
aGLa\$ataa	aG\$alataa	aLga\$ataa	aGBaFataa	aBDa\$ataa	taHaaFaNa	yuXaaWiTna
أغظوا	أغظوا	أطغوا	أغظوا	ألعظوا	انبطا	اسطربوا
aGTaVuu	aGVaTuu	aTGaVuu	aGLaHuu	aRDaVuu	inBaLaZaa	isTaRaBuu
أعظت	أعظت	أطعقت	أعصت	أجزقت	تتشفوا	تتأسفت
aEzaQtu	aEQaZtu	aZEaQtu	aEBaStu	aJzaQtu	taSaSa~Fuu	taNaaSa\$at
أغشوا	أغشوا	أغشوا	أغشوا	أثبوا	أردشوا	يماشظ
aVGa\$uu	aV\$agu	aGVa\$uu	aVbaLuu	aRDa\$uu	yatDaaXaTu	yuMaaLi\$uuna
أعظنا	أعظنا	أعظنا	أعظنا	أزبطنا	يجابتن	استظيكا
aEQaTnaa	aETaQnaa	aQEaTnaa	aEKaTnaa	aZBaTnaa	yuJaaBiTna	istaZBaKa
أعظوا	أعظوا	أعظوا	أعظوا	أعظوا	يشكظن	استجق
aMGaTuu	aMTaGuu	aGMaTuu	aM<aKuu	aRZaTuu	ya\$Kiuuna	istaJMaQa
أغشنا	أغشنا	أغشنا	أغصنا	أذسنا	نشزها	استنقه
aGHaSataa	aGSaHataa	aHGaSataa	aGJaSataa	a*<aSataa	nu\$<iZuhaa	istaVaQaHu
أعظنا	أعظنا	أعظنا	أعظنا	أعظنا	يطظون	استمظن
iEtaKaNataa	iEtaNaKataa	iKtaEaNataa	iEtaLaTataa	iDtaZaNataa	yaTNu*uuuna	istaXMaZna
أسكت	أسكت	أسكت	أسجت	أزركت	نلخبها	استنق
aSaGaKat	aSaKaGat	aGaSaKat	aSaJaHat	aZaRaKat	naLBUXUhaa	istaNTaQa
التعجوا	التعجوا	أعظوا	التعصوا	أتهجوا	ينتعفان	يصاخم
iLtaGaJuu	iLtaJaGuu	iGtaLaJuu	iLtaSa\$uu	i*taHaJuu	yanTaEiFaani	yuSaaXiMu
أعظوا	أعظوا	أعظوا	أعظوا	أيدفوا	يكفزون	استجفنا
aETaVuu	aEVaTuu	aTEaVuu	aEBaKuu	aBDaVuu	yaKFiZunna	istaJXaFnaa
أعظنا	أعظنا	أعظنا	أعظنا	أرظنا	تهبضان	يقمجا
aGSaZataa	aGZaSataa	aSGaZataa	aGSaMataa	aRZaZataa	tuHbiDaani	yaQtaMiJaa
أعظوا	أعظوا	أعظوا	أعظوا	أعظوا	يتانز ان	أبتهت
aE\$SaTuu	aETa\$uu	a\$EaTuu	aENaZuu	AD*aTuu	yataNaa<aZaani	aBTaHat
أعظوا	أعظوا	أعظوا	أعظوا	أعظوا	يحشون	يشاكنظن
iKtaEaMuu	iKtaMaEuu	iEtaKaMuu	iKtaNaSuu	iDtaZaMuu	yaH\$uNuuna	yataSaaKaDna
أغشنا	أغشنا	أغشنا	أغظنا	أغظنا	تسقدان	ينظون
aFGa\$naa	aF\$Gnaa	aGFa\$naa	aF<aTnaa	a*Za\$naa	tuSQiDaani	yaAtaFiDuuna
أعظنا	أعظنا	أعظنا	أعظنا	أعظنا	يتفجدن	تضاموا
aNEuVuhaa	aNVuEuhaa	aENuVuhaa	aNBuXuhaa	aDZuVuhaa	yataFaJaDna	taDaaMa\$uu
أعظوا	أعظوا	أعظوا	أعظوا	أعظوا	يشمون	استظفنا
aGDaLuu	aGLaDuu	aDgaLuu	aGJaQuu	aDRaLuu	yaVMuWuuna	istaQyaFaTaa
أظنعت	أظنعت	أظنعت	أظنعت	أظنعت	ينصون	تكاموا
iZtaEaSat	iZtaSaEat	iEtaZaSat	iZtaba\$at	i*taRaSat	yaB<iSuuna	taKaaMa\$uu
أعظنا	أعظنا	أعظنا	أعظنا	أعظنا	تعدظنا	ينكمجا
aJGa\$ataa	aJ\$agataa	aGJa\$ataa	aJ<aDataa	AR*a\$ataa	tuEDiZuna	yaNKaMiXaa

Note. In the appendices, the asterisk (\*) represents the Arabic letter ذ and the tilde (~) represents gemination.