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Cross-lingual phonological effects in different-script bilingual visual-word recognition

Orna Peleg
Tel-Aviv University, Israel

Tamar Degani
University of Haifa, Israel

Muna Raziq and Nur Taha
Tel-Aviv University, Israel

Abstract

To isolate cross-lingual phonological effects during visual-word recognition, Arabic–Hebrew bilinguals who are native speakers of Spoken Arabic (SA) and proficient readers of both Literary Arabic (LA) and Hebrew, were asked to perform a visual lexical-decision task (LDT) in either LA (Experiment 1) or Hebrew (Experiments 2 and 3). The critical stimuli were non-words in the target language that either sounded like real words in the non-target language (pseudo-homophones) or did not sound like real words. In Experiment 1, phonological effects were obtained from SA to LA (two forms of the same language), but not from Hebrew to LA (two different languages that do not share the same script). However, cross-lingual phonological effects were obtained when participants performed the LDT in their second language, Hebrew (Experiments 2 and 3). Interestingly, while the within-language effect (from SA to LA) was inhibitory, the between-language effect (from SA to Hebrew) was facilitatory. These findings are explained within the Bilingual Interactive Activation plus (BIA+) model which postulates a fully interconnected identification system that provides output to a task/decision system.

Keywords

cross-language influences, cross-lingual phonological effects, different-script bilinguals, pseudo-homophone, visual-word recognition

Corresponding author:
Orna Peleg, The Program of Cognitive Studies of Language and its Uses, Tel Aviv University, Tel Aviv, 69978, Israel
Email: pelegor@post.tau.ac.il

I Introduction

Substantial research on bilingual visual-word recognition demonstrates that when bilinguals identify words in one language, lexical representations of both languages (the target language and the non-target language) are activated (e.g. Brysbaert et al., 1999; Dijkstra et al., 1999). Such findings are commonly explained within the Bilingual Interactive Activation Plus (BIA+) model (Dijkstra and van Heuven, 2002), which postulates a fully interconnected identification system in which orthographic (spelling), phonological (sound) and semantic (meaning) representations are accessed in a language nonselective way. Yet, although this model allows for cross-lingual interactions at different processing levels (sub-lexical and lexical) and among different codes (orthographic, phonological and semantic), most research on this issue focused on cross-lingual interactions at the orthographic level with same-script bilinguals (e.g. Caramazza and Brones, 1979; De Groot et al., 2000). The present study therefore aimed to investigate whether cross-lingual interactions during visual-word recognition can occur via phonological rather than orthographic representations.

To distinguish between orthographic and phonological effects, several studies have manipulated the degree of phonological overlap between words in two different languages that share the same script (e.g. Brysbaert et al., 1999; Dijkstra et al., 1999; Duyck, 2005; Lemhöfer and Dijkstra, 2004; van Wijnendaele and Brysbaert, 2002). The results show that the degree of phonological overlap modulated the cross-lingual effect. However, although degree of orthographic relatedness was carefully controlled (e.g. Duyck, 2005), because the shared phonological representations were also orthographically similar to some degree, the cross-lingual phonological effects reported in these studies were never completely independent of orthography.

To completely rule out orthographic effects, the present study focused on different-script bilinguals. Specifically, the participants were Arabic speakers living in Israel, whose social-linguistic setting requires them to become proficient in Spoken Arabic (SA), Literary Arabic (LA), and Hebrew. SA is a colloquial dialect, used for daily informal communication, and is the native language of all Arabic speakers (L1). LA is encountered later in life, and is used for formal communication, reading and writing (diglossia; e.g. Abu-Rabia et al., 2003; Saiegh-Haddad, 2005).[1] In the current population, Hebrew is encountered even later in life, and is learned formally in school (L2). Importantly, interactions between SA, LA and Hebrew can only occur via shared phonological or semantic codes, because LA and Hebrew do not share the same script, and SA does not involve orthographic representations because it is only a spoken dialect.

Previous studies that examined different-script bilinguals typically compared the processing of cognates (translation equivalents that are also phonologically similar) and non-cognates (translation equivalents that are not phonologically similar) using the masked translation-priming paradigm (Gollan et al., 1997; Kim and Davis, 2003; Nakayama et al., 2013; and for a different paradigm, see Miwa et al., 2014). These studies indicate that cross-lingual phonological interactions can occur even in the absence of orthographic overlap. In particular, their results show that (1) L2 words are recognized faster when preceded by their L1 translations than by unrelated words; (2) These automatic cross-lingual semantic effects are stronger in the case of cognates than in the case of non-cognates. Nevertheless, because cognates are not only phonologically similar, but also semantically similar, these phonological effects may be semantically mediated. That is, phonology may be activated after semantic representations have been accessed, and or phonology may be strengthened by semantic feedback. Thus, the main aim of the present study was to investigate whether cross-lingual interactions during bilingual visual-word recognition, can occur in the absence of both orthographic and semantic overlap, only via shared phonological representations.

To dissociate phonological effects from semantic effects, some previous studies utilized non-translation stimuli with different script bilinguals, such that any cross-lingual effects can only be phonologically mediated (Dimitropoulou et al., 2011; Kim and Davis, 2003; Nakayama et al., 2012; Voga and Grainger, 2007; Zhou et al., 2010). In these studies, bilinguals performed a lexical-decision task on L2 targets that were briefly preceded by phonologically related or unrelated L1 primes. Results revealed cross-script masked phonological priming, indicating non-selective phonological activation during bilingual visual-word recognition. Nevertheless, because these studies involved cross-script priming, orthographic lexical representations of the non-target language were directly activated via the briefly presented prime. This raises the question of whether cross-lingual phonological effects can be obtained even without pre-activation of the non-target representation. Thus, to dissociate phonological effects from semantic effects in a paradigm that does not involve the pre-activation of orthographic representations in the non-target language, the present study focused on non-lexical orthographic representations. In particular, we asked whether non-lexical orthographic representations in one language can activate phonological representations in a different language, even when the two languages do not share the same script.

To accomplish this aim, SA–LA–Hebrew speakers were asked to perform a lexical-decision task in either LA (Experiment 1) or Hebrew (Experiments 2 and 3). Thus, a single-language lexical-decision task was employed. In the LA experiment, all stimuli were presented in Arabic script and participants were asked to decide whether the target is a real word in LA or not. In the Hebrew experiments, all stimuli were presented in Hebrew script, and participants were asked to perform a lexical-decision task in Hebrew. In both experiments, words corresponded to unique forms in each language (e.g. the concept BALCONY is associated with /ʃurfa/ <شرفة> in LA, /bærænda/ in SA, and /mirpeset/ מרפסת in Hebrew), such that we did not include any cognates across target and non-target languages. To isolate phonological effects two non-word conditions were compared: A pseudo-homophone condition in which non-cognates were written phonetically with a different script (see Bentin and Ibrahim, 1996; Tzelgov et al., 1996), and a non-pseudo-homophone condition. For example, in the pseudo-homophone condition, the SA word /bærænda/ which exists only in its phonological form was written phonetically in LA letters (Experiment 1, برندة) or in Hebrew letters (Experiments 2 and 3, ברנדה). In the non-pseudo-homophone condition, a letter string which did not correspond to any lexical representation in the multi-lingual lexicon, was presented in LA or in Hebrew letters across experiments. Differences between these two conditions indicate pure phonological effects. This is because orthographic effects are not possible as LA and Hebrew do not share the same script and SA does not have orthographic representations. In addition, semantic effects are not possible because we did not include cognates and importantly the critical stimuli were non-words that could only be processed via the sub-lexical phonological pathway (from orthography to phonology to semantics).

Moreover, because it is assumed that SA is more similar to LA than to Hebrew (e.g. Saiegh-Haddad and Spolsky, 2014), and Arabic speakers leaving in Israel are typically more proficient in Arabic (both SA and LA) than in Hebrew, the current study also examined the contribution of language proficiency (e.g. Basnight-Brown and Altarriba, 2007; Gollan et al., 1997), and degree of similarity between the two forms/languages (e.g. De Groot et al., 1994; Norman et al., 2016a, 2016b; van Heuven et al., 2011) to cross-lingual phonological effects.

II Experiment 1

In a previous study, Bentin and Ibrahim (1996) utilized the diglossic situation in Arabic to examine pure phonological effects in visual-word recognition. In their study (Bentin and Ibrahim, 1996; Experiment 2), participants who were native Arabic speakers living in Israel were asked to perform a lexical-decision task in LA. The stimuli were (1) LA real words that do not exist in SA (2) LA non-words that were phonetic transliterations of words that exist only in SA (SA pseudo-homophones), and (3) LA non-words that did not sound like real words in SA or LA (non-pseudo-homophones). Similar to the monolingual pseudo-homophone effect (e.g. English non-words (BRANE) that sound like real words (*brain*); (e.g. Rubenstein et al., 1971; van Orden, 1987; Ziegler et al., 2001), Bentin and Ibrahim observed that SA pseudo-homophones were more difficult to reject (slower reaction times) than non-pseudo-homophones. Thus, orthographic representations in LA automatically activated phonological representations that exist only in SA, even when the task was restricted to LA. These results suggest that phonological influences in visual-word recognition can be obtained even without orthographic or semantic overlap.

Nevertheless, given that LA and SA are considered two forms of the same language, a question arises as to whether such 'pure' phonological effects can also be found between two different languages (e.g. LA and Hebrew). Although a cross-lingual pseudo-homophone interference effect has already been demonstrated by Nas (1983), this cross-lingual phonological effect was obtained with Dutch- English bilinguals whose two languages share the same script. Thus, the aim of our first experiment was to both replicate and expand these results by focusing on languages that do not share the same script. In particular, we aimed to extend Bentin and Ibrahim's study by including not only phonetic transliteration of SA words that do not exist in LA, but also phonetic transliteration of Hebrew words that do not exist in LA. As mentioned above, the sociolinguistic setting of Arabic speakers in Israel leads native speakers of SA to become proficient LA–Hebrew readers. If bidirectional orthographic-phonological interactivity manifests itself not only within a single language (e.g. Rubenstein et al., 1971), between two different variants of the same language (Bentin and Ibrahim, 1996), or between two languages that share the same script (Nas, 1983), but also between two orthographically distinct languages, then LA non-words that sound like Hebrew should be processed differently than LA non-words that do not sound like real words. In addition, if these phonological effects are modulated by language proficiency (e.g. Basnight-Brown and Altarriba, 2007), and degree of similarity between the languages (e.g. De Groot et al., 1994; Norman et al., 2016a, 2016b), then stronger effects are expected for SA pseudo-homophones than for Hebrew-pseudo-homophones. This is because SA is the participants' L1 and it is also more similar to LA than Hebrew (e.g. Russak and Fragman, 2014). Thus, we expect differences between the three types of non-words (SA pseudo-homophones; Hebrew pseudo-homophones; non-pseudo-homophones).

1 Method

a Participants. Participants were 20 SA–LA–Hebrew speakers (10 males) who were native Arabic speakers living in Israel. They have learned Hebrew in school, and were relatively proficient in Hebrew. In this and the following experiments, at the time of testing, all participants were university students in which all academic work is conducted in Hebrew. Further, all participants were moderately proficient in English, as is typical of the population in Israel. One participant was excluded because he has been exposed to another language from childhood. Details regarding the final set of 19 participants are presented in Table 1.

b Stimuli. Stimuli consisted of 160 LA letter strings written in the partially voweled script system[2] which convey full phonological information. Of these, 80 were real words in LA and 80 were non-words in LA. Importantly, a quarter of the non-words sounded like real SA words ('SA pseudo-homophones', $n = 20$), a quarter sounded like real Hebrew words ('Hebrew pseudo-homophones', $n = 20$) and half did not sound like any other word ('non-pseudo-homophones', $n = 40$). Stimuli were selected following a series of norming studies, as detailed below (for a complete list of experimental stimuli, see Appendix 1).

First, an initial list of LA letter strings (half real words and half non-words, which either sound or do not sound like real words in SA or Hebrew) was created by an SA–LA–Hebrew proficient speaker (author NT), such that it did not include any cognates across target and non-target languages. Moreover, non-words were all pronounceable, and SA/Hebrew pseudo-homophones were all words that could be expressed in LA letters. To verify this initial selection, 10 native Arabic speakers from a similar background who did not participate in the experimental task received this list and were asked to make three decisions regarding each item:

1. make an LA lexical decision (i.e. is this a real word in LA?);
2. rate the items marked as real words for familiarity on a scale of 1 to 7, with 1 indicating an 'extremely rare word' and 7 indicating a 'very familiar word'. Familiarity was defined to participants as 'the degree to which you come in contact with or think about the word in your daily life';
3. make a general phonological lexical-decision task on the items marked as real words (i.e. identifying cognates: does this letter string sound like a familiar word in any language other than LA?), and on the items marked as non-words (i.e. identifying pseudo-homophones: does this letter string sound like a familiar word in any language you are familiar with?).

Table 1. Mean characteristics (SD) of Experiment 1, 2, and 3 participants by language background.

	Experiment 1	Experiment 2		Experiment 3	
Group	SA–LA–Hebrew	SA–LA–Hebrew	Native Hebrew	SA–LA–Hebrew	Native Hebrew
Age	22.2 (2.9) $_{a,c}$	22.7 (3.4) $_{a,c}$	25.5 (4.3) $_{b}$	21.4 (2.0) $_{a}$	25.1 (3.9) $_{b,c}$
Native language	SA	SA	Hebrew	SA	Hebrew
Hebrew age of acquisition (years)	7.7 (1.6) $_{a}$	7.4 (1.1) $_{a}$	birth	7.9 (1.7)$_{a}$	birth
Hebrew proficiency	8.7 (0.7) $_{a}$	8.7 (1.3) $_{a}$	9.8 (.4) $_{b}$	8.5 (.7) $_{a}$	9.5 (.5) $_{b}$
Hebrew reading proficiency	9.0 (0.8) $_{a,b}$	8.8 (1.9) $_{a}$	9.8 (.4) $_{b}$	8.6 (.9) $_{a}$	9.7 (.5) $_{b}$
Hebrew use	6.6 (1.3) $_{a,b}$	6.1 (1.9) $_{a}$	7.7 (1.4) $_{b,c}$	6.6 (1.6) $_{a,b}$	8.4 (1.1) $_{c}$
Arabic proficiency	9.2 (1.1) $_{a}$	9.6 (.5) $_{a}$	n/a	9.6 (.6) $_{a}$	n/a
Arabic reading Proficiency	9.0 (1.4) $_{a}$	9.8 (.4) $_{b}$	n/a	9.7 (.6) $_{a,b}$	
Arabic use	6.5 (1.5) $_{a}$	7.6 (1.6) $_{a}$	n/a	6.6 (2.3) $_{a}$	n/a
Mean lexical decision accuracy	.93 (.05) $_{a,c}$	.95 (.04) $_{a,b}$	.99 (.01) $_{b}$	.90 (.07) $_{c}$	.98 (.02) $_{b}$
Mean total lexical decision RT	1047.66 (310.14) $_{a}$	1199.33 (436.14) $_{a}$	705.43 (162.55) $_{b}$	1288.41 (372.75) $_{a}$	631.32 (106.04) $_{b}$
Mean non-word (no) decision RT	1166.95 (397.58) $_{a}$	1341.86 (531.72) $_{a,b}$	739.92 (178.75) $_{c}$	1551.38 (518.39) $_{b}$	662.82 (121.13) $_{c}$

Note. RT = reaction time; LA = Literary Arabic; SA = Spoken Arabic. Proficiency scores are the average of self-rated proficiency in reading, writing, conversation and oral comprehension on a scale of 0 to 10, where 0 indicates lower ability and 10 indicates highest ability. Use scores are the averages of self-rated use speaking, reading, writing, listening to radio and watching TV, on a scale of 0 to 10, where 0 indicates lower usage and 10 indicates highest usage. Means in the same row that do not share an alphabetic subscript differ at the $p < .05$ level based on t-tests between the conditions with Bonferroni corrections for multiple comparisons.

Based on these procedures, real LA words were selected if they received an average familiarity of above 5, and if all participants agreed that they did not sound like a word in SA, Hebrew, or any other language they know. Non-pseudo-homophones were selected if all participants agreed that they did not sound like a real word in any language they know. Conversely, Hebrew pseudo-homophones and SA pseudo-homophones were selected if all participants agreed that they sound like a real word in Hebrew or in SA, respectively. Regarding Hebrew pseudo-homophones and SA pseudo-homophones (all non-words in LA), the same participants were asked to (1) rate how familiar is the SA or Hebrew word on a scale of 1–7, with 1 indicating 'an extremely rare word' and 7 indicating 'a very familiar word'; and (2) provide the meaning of the SA/Hebrew word in LA. Items that received a familiarity score of above 5 and the same meaning was given by all participants were selected as the final Hebrew or SA pseudo-homophones.

Following these series of norms, the final set of items was selected with 80 real LA words which are non-cognates with SA or Hebrew, and are relatively familiar; 40 non-pseudo-homophones which do not sound like a real word in Hebrew, in SA or in LA; 20 SA pseudo-homophones which do not sound like a real word in Hebrew or in LA, but do sound like a familiar word in SA; and 20 Hebrew pseudo-homophones which do not sound like a real word in SA or in LA, but do sound like a familiar word in Hebrew. All items were 2 to 7 letters long, and were matched on length across conditions, as well as on subjective familiarity (see Table 2). In addition, mean bigram and trigram orthographic frequencies, as well as orthographic neighborhood size were calculated based on a corpus of 10 million words (a collection of articles from the LA newspaper Al-Watan). Finally, morphological regularity scores (0, 1 or 2) were computed by examining whether each non-word stimuli includes a real root and a real word pattern in LA: 0 = a letter string with no familiar root and no familiar word pattern; 1 = a letter string with either a familiar root or a familiar word pattern; 2 = a letter string with both a familiar root and a familiar word pattern. Details regarding the different non-word types are presented in Table 2. When comparisons across non-word types revealed significant differences, these were taken into account in the analysis of the results.

c Procedure. Each participant completed the task individually in a quiet room, in a session that lasted approximately 40 minutes. The entire experiment was conducted in Arabic. Each trial in the lexical-decision task began with a fixation cross for 500 ms followed by the target letter string for LA lexical decision. The target remained on the screen until the participant made a yes/no decision by pressing the corresponding key on the response box. Participants were instructed to respond as quickly and accurately as possible whether the target stimulus was a real word in LA or not, and response times and accuracy were recorded by the computer program (E-Prime software; Psychology Software Tools, Pittsburgh, PA). Each participant saw all 160 letter strings (80 real words, 40 non-pseudo-homophones, 20 SA pseudo-homophones, and 20 Hebrew pseudo-homophones) in a randomized order, presented in 8 blocks interleaved with short breaks. Ten practice trials preceded the experimental trials. To ensure that the intended phonological representations was indeed extracted from the sub-lexical orthographic representation, a post-test was included in which participants were asked to name the stimuli out-loud and their responses were recorded. Finally, participants completed an Arabic version of

Table 2. Mean characteristics of Experiment 1, 2, and 3 stimuli by non-word type.

	Experiment 1 (LA LDT)			Experiment 2 (Hebrew LDT)		Experiment 3 (Hebrew LDT)		
Non-word Type	SA pseudo homophones	Hebrew pseudo homophones	Non-Pseudo homophones	SA pseudo homophones	Non-Pseudo homophones	SA pseudo homophones	LA pseudo homophones	Non-Pseudo homophones
Number of items	20	20	40	50	50	20	20	40
Length (in letters)	4.30 (.98) $_{a}$	4.70 (.57) $_{a}$	4.33 (.62) $_{a}$	4.56 (.73) $_{a}$	4.44 (.50) $_{a}$	4.40 (.75) $_{a}$	4.56 (.62) $_{a}$	4.53 (.64) $_{a}$
Familiarity (1–7)	5.51 (1.95) $_{a}$	6.45 (.49) $_{b}$	n/a	6.65 (.45) $_{a}$	n/a	6.33 (.59) $_{a}$	6.44 (.47) $_{a}$	n/a
Bigram frequency	.0007 (.0006) $_{a,e}$	.0010 (.0006) $_{a,c,e}$	.0006 (.0006) $_{e}$	.0018 (.0009) $_{c,f,g}$	.0014 (.0008) $_{a,f}$	.0027 (.0021) $_{b}$	.0022 (.0014) $_{b,f}$	.0023 (.0010) $_{b,g}$
Trigram frequency	.00002 (.00004) $_{a,`c}$	.00005 (.00004) $_{a,`d,i}$	.00004 (.00008) $_{a,`e}$	00008 (.00010) $_{a,f}$	.00005 (.00007) $_{a,g}$	.00016 (.00025) $_{b,`d,f,h}$	.0001 (.00011) $_{a,h}$	.0001 (.00011) $_{`c,`e,f,g,h,i}$
Orthographic neighborhood	37.87 (19.31) $_{a,c}$	45.10 (26.46) $_{a}$	29.51 (21.03) $_{c,d}$	11.74 (11.04) $_{b}$	10.98 (9.52) $_{b}$	17.60 (10.66) $_{b,d}$	15.44 (12.38) $_{b}$	16.18 (11.85) $_{b}$
Morphological regularity (0–2)	1.10 (.55) $_{a,c}$	1.15 (.37) $_{a,`d}$	0.88 (.34) $_{a,b,c}$	0.54 (.58) $_{b,e}$	0.60 (.61) $_{b,e}$	0.50 (.61) $_{b,e}$	0.60 (.75) $_{c,`d,e}$	0.60 (.63) $_{b,e}$

Note. LDT = lexical-decision task. Means in the same row that do not share an alphabetic subscript differ at the $p < .05$ level based on t-tests between the conditions with Bonferroni corrections for multiple comparisons. ` marks a marginally significant difference with $p < .1$. Standard deviations are given in parenthesis.

a language-history questionnaire in which they rated their proficiency and use in each language (adapted from LEAP-Q; Marian et al., 2007).

2 Results

Reaction time (RT) data and accuracy data were analysed using a linear mixed effects (LME) model (Baayen et al., 2008) as implemented in the lme4 library in R (version 3.3.3, R Core Team, 2017). This computation allows the testing of hypotheses while taking into account the variance due to participants and to items simultaneously. Our major hypothesis relates to the difference in response times between LA non-words that sound like SA / Hebrew words, and LA non-words that do not sound like familiar words. Thus, the main model was constructed with the effect of Nonword Type (SA pseudo-homophone, Hebrew pseudo-homophone, or Non-pseudo-homophone) as a fixed factor, and the effects of Participants and Items as random factors. In addition, the effects of Bigram Frequency, Trigram Frequency, Orthographic Neighborhood Size, and Morphological Regularity, were taken into account as fixed effects.

a Reaction time data. Reaction time data were calculated on correct responses only. Reaction times that were less than 300 ms or more than 5,000 ms were excluded as cutoffs, and those that were more than 2.5 standard deviations from the mean for each participant on correct responses were trimmed as outliers (less than 4% of the data).

First, as is typical of lexical-decision tasks, a preliminary model with the effect of Lexicality (word vs. non-word) as a fixed factor and the effects of Participants and Items as random factors, revealed a main effect for lexicality $F(1, 143.4) = 98.7$, $p < .001$, indicating that words were responded to more quickly ($M = 992.8$; $SE = 85.1$) than non-words ($M = 1225.4$; $SE = 85.2$). To examine cross-lingual interaction, additional analyses were conducted only on the data from the non-word condition. First, a baseline model was constructed with the effects of Bigram Frequency, Trigram Frequency, Orthographic Neighborhood Size, and Morphological Regularity as fixed effects, and the effects of Participants and Items as random factors. Within this model, no main effects were found (all Fs < 1), indicating that none of these control variables correlated with RT. Thus, these variables were not included in the main model which was constructed with the effect of Nonword Type (SA pseudo-homophone, Hebrew pseudo-homophone, or non-pseudo-homophone) as a fixed factor and the effects of Participants and Items as random factors.

Within this model, the effect of Non-word Type was significant, $F\,(2, 75.9) = 12.01$, $p < .001$. Testing the simple effects with Bonferroni corrections revealed that SA pseudo-homophones were significantly slower ($M = 1389.4$; $SE = 107.8$) than non-pseudo-homophones ($M = 1203.3$; $SE = 103.7$), $\chi^2\,(1) = 16.9$, $p < .001$; and Hebrew pseudo-homophones ($M = 1150.9$; $SE = 106.5$), $\chi^2\,(1) = 21.65$, $p < .001$; but that the latter two non-word types did not differ from each other, $\chi^2\,(1) = 1.55$, *NS* (see Figure 1).

b Accuracy data. The same analyses were done on accuracy data, using the binomial distribution. First, as is typical of lexical-decision tasks, words were responded to significantly more accurately ($M = .99$) than non-words ($M = .96$), $p < .001$. Second, within

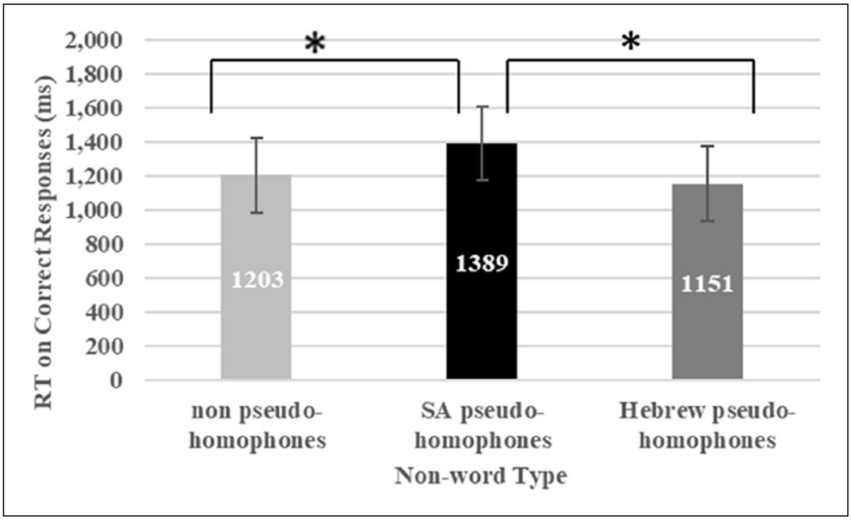

Figure 1. Reaction time (RT) on correct responses to non-words as a function of non-word type in a Literary Arabic (LA) lexical-decision task (Experiment 1).
Notes. Error bars represent the 95% confidence intervals. * Significant at $p < 0.05$. SA = Spoken Arabic.

the baseline model, the effect of Morphological Regularity was marginally significant ($\beta = -.39$, $SE = .22$, $Z = -1.8$, $p = 0.07$) and was therefore retained, creating a baseline model with just this variable. This baseline model was then compared with a model that included not only the effect of Morphological Regularity, but also the effect of Non-word Type. Importantly, a comparison between these two models revealed that the model that included the effect of non-word type resulted in a better fit for the data (χ^2 (2) = 60.84, $p < 0.001$), and was therefore selected for further analysis. Testing the simple effects of the significant Non-word Type with Bonferroni corrections revealed that SA pseudo-homophones were significantly less accurate ($M = 0.76$) than non-pseudo-homophones ($M = 0.97$), χ^2 (1) = 60.5, $p < .001$; and Hebrew pseudo-homophones ($M = 0.98$), χ^2 (1) = 50.8, $p < .001$; but that the latter two non-word types did not differ from each other, χ^2 (1) = 0.78, *NS* (see Figure 2).

3 Discussion

The findings of Experiment 1 are consistent with the findings reported by Bentin and Ibrahim (1996), demonstrating pure phonological influences in visual-word recognition. Specifically, LA non-words that sounded like real words in SA were more difficult to reject in comparison to LA non-words that did not sound like real words, suggesting that competition from SA may hinder LA processing (see also Saiegh-Haddad et al., 2011). In particular, these results can provide an explanation for the finding that native Arabic speakers have more difficulty processing structures that are not identical in SA and LA (e.g. Saiegh-Haddad and Schiff, 2016).

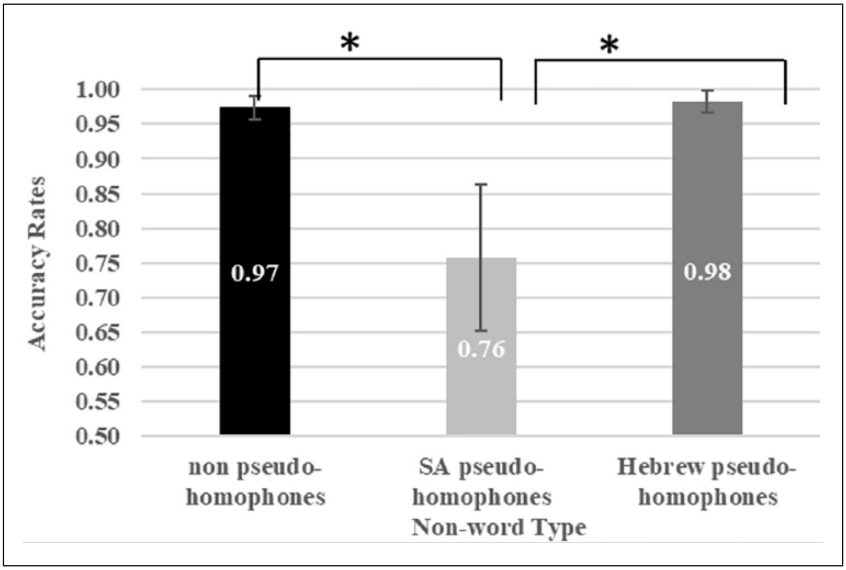

Figure 2. Accuracy on non-words as a function of non-word type in a Literary Arabic (LA) lexical-decision task (Experiment 1).
Notes. Error bars represent the 95% confidence intervals. * Significant at $p < 0.05$. SA = Spoken Arabic.

Interestingly, cross-lingual phonological effects (from Hebrew to LA) were not obtained, as LA non-words that sounded like real words in Hebrew (L2) were processed similarly to LA non-words that did not sound like real words. A possible interpretation for these patterns may be related to the degree of similarity between LA and SA or Hebrew. As mentioned above, LA and SA are considered two forms of the same language and are therefore more similar than LA and Hebrew (for a detailed description of the relation between SA and LA, and between Hebrew and SA and LA, see Ibrahim, 2006; Saiegh-Haddad and Henkin-Roitfarb, 2014; Saiegh-Haddad and Spolsky, 2014). Moreover, while SA does not have orthographic representations, LA and Hebrew have distinct orthographies, which may result a much larger distance between them. Thus, it could be the case that cross-lingual phonological effects require a high degree of similarity, which does not exist for LA and Hebrew. In other words, it is possible that in the case of different-script bilinguals, sub-lexical phonological activation during visual word recognition is language specific.

Alternatively, the above findings of influences from SA (L1) to LA, but not from Hebrew (L2) to LA may reflect the psychological status of the different languages for these speakers. Indeed, previous research with masked translation-priming suggests stronger cross-lingual effects from the dominant L1 than from the less-dominant language (e.g. Gollan et al., 1997; for review, see Basnight-Brown and Altarriba, 2007), and specifically stronger effects from SA to LA (Ibrahim and Aharon-Peretz, 2005). To examine these interpretations further we conducted Experiment 2, in which we examined Arabic–Hebrew phonological interactions from the opposite direction. Namely, SA–LA–Hebrew speakers were asked to perform a visual lexical-decision task in Hebrew (L2), in which non-words either sounded like real words in SA (L1) or did not sound like a real word in any language known to participants. In this scenario, the psychological status of the pseudo-homophones is strong, because SA is the dominant language, whereas the distance between the two languages (SA and Hebrew) remains large. Thus, if pure cross-lingual phonological effects can occur between orthographically distinct languages then SA effects are expected during visual lexical decisions in Hebrew.

III Experiment 2

1 Method

a Participants. Participants were 27 SA–LA–Hebrew speakers (8 males) and 26 native Hebrew control participants with no knowledge in Arabic (8 males).[3] Six participants (3 SA–Hebrew bilinguals and 3 Hebrew speakers) were excluded because they have been exposed to another language from childhood. Details regarding the final set of 47 participants are presented in Table 1.

b Stimuli. Stimuli consisted of 200 Hebrew letter strings written in the voweled script system, which convey full phonological information. Of these, 100 were real Hebrew words and 100 were non-words in Hebrew. Importantly, half of the non-words sounded like real SA words ('SA pseudo-homophones'), and half did not ('non-pseudo-homophones'). Stimuli were selected following a series of norming studies, as detailed below (for a complete list of experimental stimuli, see Appendix 1).

First, an initial list of Hebrew letter strings (half real words and half non-words, which either sound or do not sound like real words in SA) was created by an SA–LA–Hebrew proficient speaker (author MR), such that it did not include any cognates across target and non-target languages. Moreover, non-words were all pronounceable, and SA pseudo-homophones could be expressed by Hebrew letters. To verify this initial selection, in the first phase, 10 native Hebrew speakers who did not participate in the experimental task and do not know Arabic received this list of Hebrew letter strings and were asked to make four decisions regarding each item:

1. make a Hebrew lexical decision;
2. rate the items marked as real words for familiarity on a scale of 1 to 7;
3. make a general phonological lexical-decision task on the items marked as words;
4. make a general phonological lexical-decision task on the items marked as non-words.

Based on these procedures, real words were selected if they received an average familiarity of above 5, and did not sound like a word in any other language these participants may have knowledge of (e.g. English). Non-words were selected if they did not sound like a real word in Hebrew or in any other language known to participants.

In the second phase, 10 SA–LA–Hebrew speakers who did not participate in the main experiment were asked to similarly make a Hebrew lexical-decision on these items and judge the familiarity of the real words on a 1–7 scale. Further, they were asked to judge whether the real Hebrew words sound like a familiar word in any other language they know. Following these procedures, real Hebrew words were selected if they received a familiarity score of above 5 and did not sound like a word in any other language (i.e. are not cognates). Regarding the items that were marked as non-words, participants were asked to make a general phonological lexical-decision task. Based on these procedures non-pseudo-homophones were selected if all participants agreed that they did not sound like a real word in any language they know. SA pseudo-homophones were selected if all participants agreed that they sound like a real word in SA. Regarding SA pseudo-homophones, the same 10 participants rated how familiar is the SA word on a scale of 1–7, and provided the meaning of the SA word in Hebrew. Items that received a familiarity score of above 5 and the same Hebrew meaning across participants were selected as SA pseudo-homophones.

Following these norming procedures, the final set of items was selected with 100 real Hebrew words which are non-cognates with any other language known to participants, and are relatively familiar; 50 non-pseudo-homophones which do not sound like a real word in any other language known to participants; and 50 SA pseudo-homophones which do not sound like a real word in Hebrew, but do sound like a familiar word in SA. All items were 3 to 6 letters long, and were matched on length across conditions (see Table 2) In addition, mean bigram and trigram orthographic frequencies, as well as orthographic neighborhood size were calculated based on a corpus of 12 million words (a collection of articles from the Hebrew newspaper *Haaretz*).[2] Further, morphological regularity was computed as in Experiment 1. Details regarding the different non-word types are presented in Table 2, and any observed differences were taken into account in the analysis of the results.

c Procedure. The procedure was identical to that of Experiment 1, with three exceptions. (1) The entire experiment, including instructions and language-history questionnaire (LHQ) was conducted in Hebrew. (2) Participants were instructed to respond whether the target stimulus was a real word in Hebrew or not. (3) There were 200 letter strings (100 real words, 50 non-pseudo-homophones and 50 SA pseudo-homophones).

2 Results

RTs and accuracy data from Experiment 2 were similarly analysed using a linear mixed effects (LME) model (Baayen et al., 2008) as implemented in the lme4 library in R (version 3.3.3, R Core Team, 2017). Our major hypothesis relates to the difference (in terms of RTs and accuracy rates) between Hebrew non-words that sound like SA words, and Hebrew non-words that do not sound like familiar words in the SA–LA–Hebrew group. Thus, the main model was constructed with the effect of Non-word Type (SA pseudo-homophone or non-pseudo-homophone) and Language Group (SA–LA–Hebrew vs. native Hebrew) as fixed factors, and the effects of Participants and Items as random factors. In addition, the effects of Bigram Frequency, Trigram Frequency, Orthographic Neighborhood Size, and Morphological Regularity, were taken into account as fixed effects.

a Reaction time data. As in Experiment 1, reaction time data were calculated on correct responses only, and identical trimming procedures were applied (resulting in exclusion of less than 4% of the data). The analysis of RT revealed that a preliminary model with the fixed factors Lexical Status (word vs. non-word) and Language Group (SA–LA–Hebrew vs. native Hebrew) in a two-way interaction, and the random factors of Participants and Items, resulted in the best fit for the data, χ^2 (1) = 191. 7, $p < .001$, relative to the model that included only the main effects. Within this model, as is typical of lexical-decision tasks, a main effect for lexical status was found, F (1, 191.8) = 132.5, $p < .001$, indicating that words were responded to more quickly (M = 871.4; SE = 49.4) than non-words (M = 1043.3; SE = 49.5). In addition, the main effect for Language Group was significant, F (1, 45) = 26.49, $p < .001$, indicating that native Hebrew speakers responded more quickly (M = 708; SE = 69.5) than SA–LA–Hebrew speakers (M = 1206.7; SE = 68.1). Finally, the interaction between Lexical Status and Language Group was significant, F (1, 8524.3) = 193.8, $p < .001$. To follow up on this two-way interaction, we analysed the effect of Lexical Status in each Language Group, using the Bonferroni adjustment. This analysis showed that the Lexical Status effect was more pronounced for SA–LA–Hebrew speakers (M = 1069.6 for words vs. M = 1343.8 for non-words) than for native Hebrew speakers (M = 673.2 for words vs. M = 742.9 for non-words), but was significant in both groups, for SA–LA–Hebrew speakers, χ^2 (1) = 270.6, $p < .001$ and for native Hebrew speakers, χ^2 (1) = 17.6, $p < .001$.

To examine cross-lingual interaction, additional analyses were conducted only on the data from the non-word condition. First, a baseline model was constructed with the effects of Bigram Frequency, Trigram Frequency, Orthographic Neighborhood Size, and Morphological Regularity as fixed effects, and the effects of Participants and Items as random factors. Within this model, the main effect of Orthographic Neighborhood Size was marginally significant F (1, 92.6) = 3.6, p = .06, and was therefore taken into account in the main model which was constructed to examine the effects of Non-word Type and Language Group. Specifically, three models were compared: The first model included the fixed main effects of Orthographic Neighborhood Size, Non-word Type and Language Group and the random effects of Participants and Items. The second model included in addition the two-way interaction between Non-word Type and Language Group, and the third model included in addition the three-way interaction between Orthographic Neighborhood Size, Non-word Type and Language Group.

Comparisons across these three models revealed that the second model – including the fixed main effects of Orthographic Neighborhood Size, Non-word Type and Language Group, the interaction between Non-word Type and Language Group, and the random effects of Participants and Items – results in the best fit for the data χ^2 (1) = 45.9, $p < .001$. Within this model, there was a significant main effect of Orthographic Neighborhood Size, β = 26.93, SE = 9.78, F (1, 93.5) = 7.6, p = .01; a significant main effect of Non-word Type, F (1, 44.9) = 27, $p < .001$; and a significant main effect of Language group, F (1, 92) = 15.6, $p < .001$. Importantly, the two-way interaction between Non-word Type and Language Group was significant, F (1, 4173.6) = 46.1, $p < .001$.

In order to follow up on this two-way interaction, we analysed the effect of Non-word Type in each Language Group, using the Bonferroni adjustments. This analysis revealed that whereas SA–LA–Hebrew speakers responded more quickly to SA pseudo-homophones

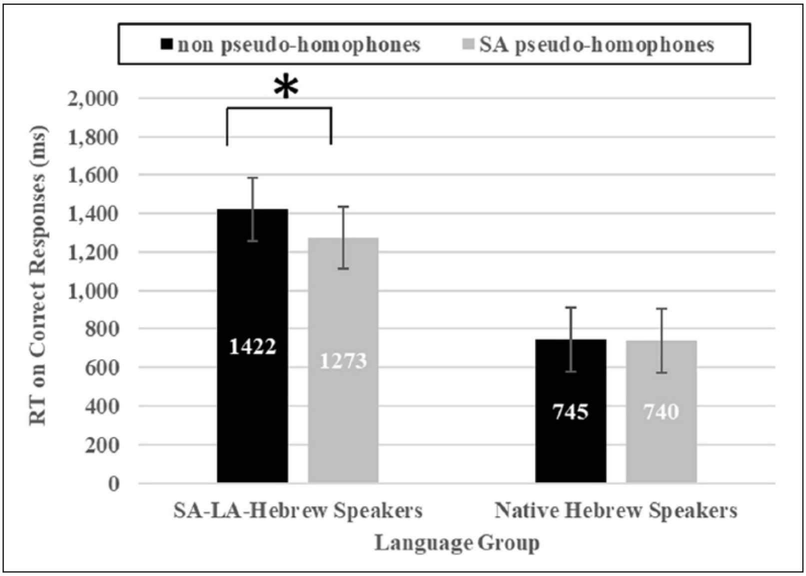

Figure 3. Reaction time (RT) on correct responses to non-words as a function of language group and non-word type in a Hebrew lexical-decision task (Experiment 2).
Notes. Error bars represent the 95% confidence intervals. * Significant at $p < 0.05$. SA = Spoken Arabic; LA = Literary Arabic.

(M = 1273.1; SE = 82.6) than to non-pseudo-homophones (M = 1421.9; SE = 82.7), χ^2 (1) = 44. 8, $p < .001$, there was no significant difference between the two non-word types for native Hebrew speakers (M = 739.7; SE 84.3 vs. M = 744.8; SE = 84.3 for SA pseudo-homophones and non-pseudo-homophones, respectively), χ^2 (1) = 0.05, NS (see Figure 3).

b Accuracy data. The same analyses were conducted on the accuracy data, using the binomial distribution. First, a preliminary model with the fixed factors Lexical Status (word vs. non-word) and Language Group (SA–LA–Hebrew vs. native Hebrew) in a two-way interaction, and the random factors of Participants and Items, did not result a better fit for the data, χ^2 (1) = 1. 4, NS, relative to the model that included only the main effects. Within the selected additive model, the effect of Language Group was significant, indicating that native Hebrew speakers responded more accurately (M = .99) than SA–LA–Hebrew speakers (M = .98), $p < 0.001$. However, the effect of Lexical Status was not significant (p = .12), possibly due to a ceiling effect.

To examine cross-lingual interaction, additional analyses were conducted only on the data from the non-word condition. A baseline model revealed that the effects of all of the control variables were significant (all ps < 0.05). This baseline model was then compared with a model that also includes the effects of Non-word Type and Language Group as fixed effects, which resulted in a better fit for the data (χ^2 (2) = 60.84, $p < 0.001$). Notably, introducing the two- way interaction between Non-word Type and Language

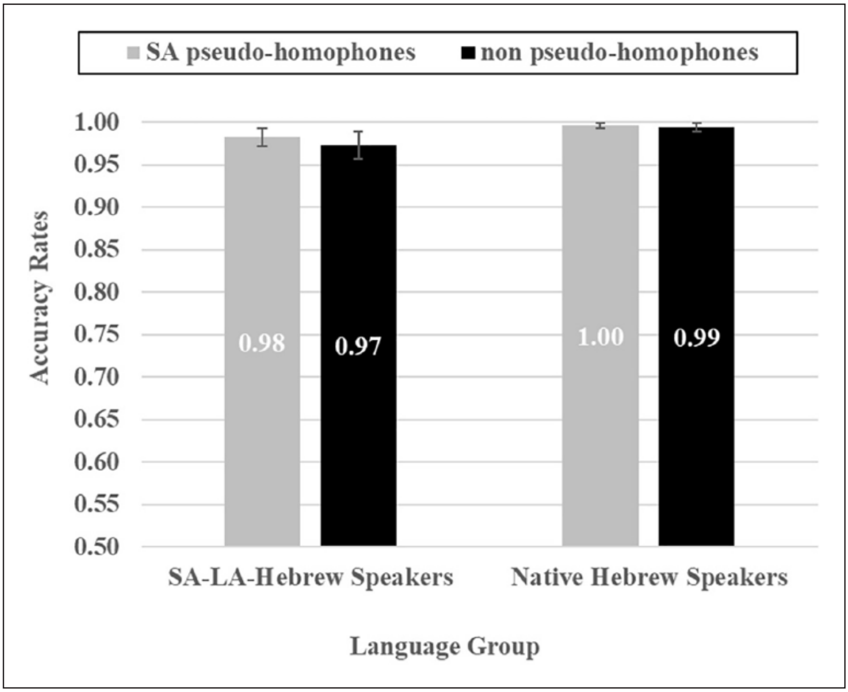

Figure 4. Accuracy on non-words as a function of non-word type in a Hebrew lexical-decision task (Experiment 2).
Notes. Error bars represent the 95% confidence intervals. SA = Spoken Arabic; LA = Literary Arabic.

Group into the model with all control variables resulted in a convergence failure. Further, excluding the control variables, the interactive model did not improve the fit over the model including only the main effects of Non-word Type and Language Group (χ^2 (1) = 0.28, p = 0.60). Thus, the model that included the main effects of Non-word Type and Language Group, in addition to the control variables, was selected for further analysis.

Within this model, the effects of Trigram frequency (β = –.52, *SE* = .21, *Z* = −2.5, p = 0.01), Orthographic Neighborhood Size (β = –.58, *SE* = .14, *Z* = –4.2, $p < 0.001$) and Morphological Regularity (β = –.35, *SE* = .14, *Z* = −2.4, p = 0.02) were significant. In addition, the effect of Language Group was significant (β = 1.53, *SE* = .35, *Z* = 4.37, $p < 0.001$), indicating that native Hebrew speakers responded more accurately (*M* = .99) than SA–LA–Hebrew speakers (*M* = .98). However, the effect of Non-word Type did not reach significance (ps > 0.12) (see Figure 4).

3 Discussion

Whereas Hebrew speakers with no knowledge of Arabic did not distinguish between the two types of Hebrew non-words, SA–LA–Hebrew speakers rejected Hebrew non-words that sounded like SA words (SA pseudo-homophones) significantly faster than

Hebrew non-words that did not sound like a real word (non-pseudo-homophones). This interaction between the type of non-word and the linguistic status of the participant demonstrate pure cross-lingual phonological effects. Specifically, sub-lexical orthographic representations in Hebrew automatically activated their corresponding SA phonological representations, even though the two languages do not share the same script. Furthermore, the fact that lexical decisions on visually presented Hebrew letter-strings were affected by these SA phonological activations suggest that (1) visual-word recognition is affected by phonological feedback (e.g. Grainger and Holcomb, 2009; Peleg and Eviatar, 2009; Seidenberg and McClelland, 1989), and (2) this bidirectional interactivity manifests itself also between two languages with distinct orthographies (Dijkstra and van Heuven, 2002).

Although our results clearly demonstrate pure cross-lingual phonological effects in visual-word recognition, even between languages that do not share the same orthography, the direction of the effect was surprising. In particular, in this experiment, Hebrew non-words that sounded like SA words were easier to reject. As mentioned above, previous studies, that utilized the same paradigm to investigate orthographic-phonological connections within a particular language (e.g. Rubenstein et al., 1971), between two forms of the same language (Bentin and Ibrahim, 1996; see also Experiment 1), or between two different languages that share the same script (Nas, 1983), reported interference rather than facilitation effects.

Because this is the first experiment to examine pseudo-homophone effect between two languages that do not share orthography, it is unclear whether the facilitation effect is incidental. Thus, to increase the confidence in this finding, (i.e. to examine whether the cross-lingual pseudo-homophone effect is indeed facilitatory in different script bilinguals), we conducted an additional experiment with different participants and with different stimuli, Moreover, to enhance comparability across experiments, in Experiment 3 both SA and LA pseudo-homophones were included.

IV Experiment 3

1 Method

a Participants. Participants were 27 SA–LA–Hebrew speakers (3 males) and 35 native Hebrew control participants with no knowledge in Arabic (9 males). Seventeen participants (4 SA–LA–Hebrew speakers and 13 Hebrew speakers) were excluded because they have been exposed to another language from childhood (4 SA–LA–Hebrew speakers and 5 native Hebrew speakers), or because the control participants indicated some proficiency in Arabic (8 Hebrew speakers). Details regarding the final set of 45 participants are presented in Table 1.

b Stimuli. Stimuli consisted of 160 Hebrew letter strings written in the voweled script system, which convey full phonological information. Of these, 80 were real Hebrew words and 80 were non-words in Hebrew. Importantly, a quarter of the non-words sounded like real SA words (‘SA pseudo-homophones’); a quarter sounded like real LA words (‘LA pseudo-homophones’), and half did not sound like a real word in either SA or in LA ('non-pseudo-homophones'). The stimuli in the 'SA pseudo-homophone' (n = 20) and in 'non-pseudo-homophone' (n = 40) conditions were new stimuli not used in Experiments 1 or 2, and were selected following the same norming procedures described in Experiment 2 (second phase with native Arabic speakers). The 80 real words were selected from the set used in Experiment 2, and the 20 'LA pseudo-homophones' were taken from Experiment 1, and transliterated into Hebrew letters (for a complete list of experimental stimuli, see Appendix 1).

The final set of items included 80 real Hebrew words which are non-cognates with any other language known to participants, and are relatively familiar; 40 non-pseudo-homophones which do not sound like a real word in any other language known to participants; 20 SA pseudo-homophones which do not sound like a real word in Hebrew or in LA, but do sound like a familiar word in SA; and 20 LA pseudo-homophones which do not sound like a real word in Hebrew or SA, but do sound like a familiar word in LA. All items were 3 to 6 letters long, and were matched on length and subjective familiarity across conditions. In addition, as in Experiment 2, mean bigram and trigram orthographic frequencies, orthographic neighborhood size and morphological regularity were calculated. Details regarding the different non-word types are presented in Table 2, and observed differences were taken into account in the analyses of the results.

c Procedure. The procedure was identical to that administered in Experiment 2, with the exception that each participant now saw 160 letter strings (80 real words, 40 non-pseudo-homophones, 20 SA pseudo-homophones, and 20 LA pseudo-homophones) in randomized order, presented in 10 blocks interleaved with short breaks.

2 Results

RTs and accuracy data were again analysed using a linear mixed effects (LME) model (Baayen et al., 2008) as implemented in the lme4 library in R (version 3.3.3, R Core Team, 2017). As in Experiment 2, our major hypothesis relates to the difference (in terms of RTs and accuracy rates) between Hebrew non-words that sound like SA / LA words, and Hebrew non-words that do not sound like familiar words, in the SA–LA–Hebrew group. Thus, the main model was constructed with the effect of Non-word Type (SA pseudo-homophone, Hebrew pseudo-homophone, or non-pseudo-homophone) and Language Group (SA–LA–Hebrew vs. native Hebrew) as fixed factors, and the effects of Participants and Items as random factors. In addition, the effects of Bigram Frequency, Trigram Frequency, Orthographic Neighborhood Size, and Morphological Regularity, were taken into account as fixed effects.

Prior to analyses, two items were excluded from the LA pseudo-homophone condition because of extremely low accuracy for both groups ($M = .40$), likely because they differed from a real Hebrew word only by slight diacritic change. Nonetheless, items in the three non-word types were still well matched on length ($F < 1$), bigram ($F < 1$) and trigram ($F(3,154) = 2.32$, $MSE = .000$, $p = .077$) frequency, as well as on orthographic neighborhood ($F < 1$) and morphological regularity ($F < 1$). Further, LA pseudo-homophones did not differ from SA pseudo-homophones on subjective familiarity ($t < 1$).

a Reaction time data. As in Experiment 1, reaction time data were calculated on correct responses only, and identical trimming procedures were applied (resulting in exclusion of less than 4% of the data).

The analysis of RT revealed that a preliminary model with the fixed factors Lexical Status (word vs. non-word) and Language Group (SA–LA–Hebrew vs. native Hebrew) in a two-way interaction, with random factors of Participants and Items, resulted in the best fit for the data, χ^2 (1) = 441. 2, $p < .001$, relative to the model that includes only the main effects. Within this interactive model, as is typical of lexical-decision tasks, a main effect for lexical status was found, F (1, 155.1) = 234, $p < .001$, indicating that words were responded to more quickly (M = 833.1; SE = 42.8) than non-words (M = 1107.7; SE = 42.9). In addition, the main effect for Language Group was significant, F (1, 42.9) = 66.9, $p < .001$, indicating that native Hebrew speakers responded more quickly (M = 633.4; SE = 59.4) than SA–LA–Hebrew speakers (M = 1307.4; SE = 58.1). Finally, the interaction between Lexical Status and Language Group was significant, F (1, 6341) = 456.8, $p < .001$. In order to follow up on this two-way interaction, we analysed the effect of Lexical Status in each Language Group, using the Bonferroni adjustment. This analysis showed that the Lexical Status effect was more pronounced for SA–LA–Hebrew speakers (M = 1063.8 for words vs. M = 1551 for non-words) than for native Hebrew speakers (M = 602.4 for words vs. M = 664.4 for non-words), but was significant in both groups, for SA–LA–Hebrew speakers, χ^2 (1) = 556.3, $p < .001$ and for native Hebrew speakers, χ^2 (1) = 9.2416, $p = .005$.

To examine cross-lingual interactions, additional analyses were conducted only on the data from the non-word condition. First, a baseline model was constructed with the effects of Bigram Frequency, Trigram Frequency, Orthographic Neighborhood Size, and Morphological Regularity as fixed effects, and the effects of Participants and Items as random factors. Within this model, only the effect of Morphological Regularity was significant F (1, 72.2) = 4.2, $p = .05$, and was therefore taken into account in the models constructed to examine the effects of Non-word Type and Language Group. Model comparisons revealed that the model including the interaction between Non-word Type and Language Group, in addition to the main effects of Non-Word Type, Language Group and Morphological Regularity as fixed factors, with participants and items as random factors, resulted in a better fit than the additive model including only the main effects χ^2 (2) = 16.9, $p < .001$. Allowing Morphological Regularity to interact with Language Group did not improve the fit χ^2 (1) = 0.22, $p = .66$.

Within the interactive model, there was a significant main effect of Morphological Regularity, β = 27, SE = 12, F (1, 75.5) = 5.1, $p = .03$; a significant main effect of Non-word Type, F (2, 73.2) = 3.8, $p = .03$; and a significant main effect of Language group, F (1, 42.9) = 59.5, $p < .001$. Importantly, the two-way interaction between Non-word Type and Language Group was significant, F (2, 2994.6) = 8.5, $p < .001$.

In order to follow up on this two-way interaction, we analysed the effect of Non-word Type in each Language Group, using the Bonferroni adjustments. These analyses revealed that whereas the effect was not significant for native Hebrew speakers (SA pseudo-homophones: M = 663.7; SE = 85. 2; Hebrew pseudo-homophones: M = 654.8; SE = 85.7; and non-pseudo-homophones: M = 667.5; SE = 82.9; all P's NS), SA–LA–Hebrew speakers responded more quickly to SA pseudo-homophones

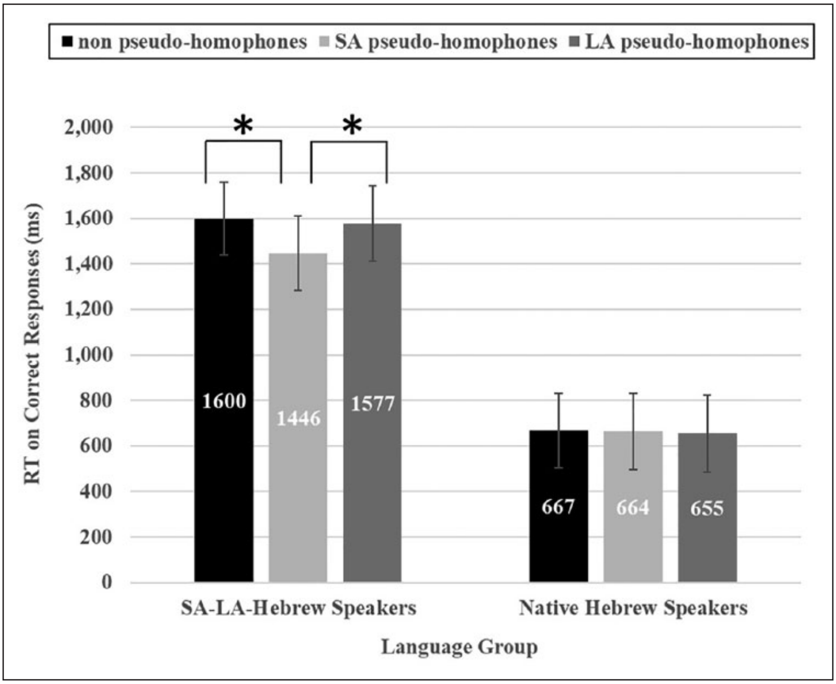

Figure 5. Reaction time (RT) on correct responses to non-words as a function of language group and non-word type in a Hebrew lexical-decision task (Experiment 3).
Notes. Error bars represent the 95% confidence intervals. * Significant at $p < 0.05$. SA = Spoken Arabic; LA = Literary Arabic.

(M = 1445.6; SE = 83.8) than to non-pseudo-homophones (M = 1599.8; SE = 81.4), χ^2 (1) = 19. 4, $p < .001$, or LA pseudo-homophones (M = 1576.6; SE = 84.2), χ^2 (1) = 10. 2, p = .008; with no significant difference between the latter two types, χ^2 (1) = 0.42, *NS* (see Figure 5).

b Accuracy data. The same analyses were done on the accuracy data, using the binomial distribution. First, a preliminary model with the fixed factors Lexical Status (word vs. non-word) and Language Group (SA–LA–Hebrew vs. native Hebrew) in a two-way interaction, and the random factors of Participants and Items, resulted in a better fit to the data, χ^2 (1) = 12. 3, $p < .001$, relative to the model including only the main effects. Within this model, as is typical of lexical-decision tasks, a main effect for lexical status was found, indicating that words were responded to more accurately (M = .98) than non-words (M = .97), $p < 0.001$. In addition, the main effect of Language Group was significant, indicating that native Hebrew speakers responded more accurately (M = .99) than SA–LA–Hebrew speakers (M = .95), $p < 0.001$. Finally, the interaction between Lexical Status and Language Group was significant, $p < 0.001$. In order to follow up this two-way interaction, we analysed the effect of Lexical Status in each Language Group, using the Bonferroni adjustments. This analysis revealed that the effect of Lexical Status was significant in the case of SA–LA–Hebrew speakers, χ^2 (1) = 29.1, $p < .001$; but not in the case of native Hebrew speakers, χ^2 (1) = 0.01, NS (probably due to a ceiling effect).

To examine cross-lingual interactions, additional analyses were conducted only on the data from the non-word condition. In analyses of the baseline model with the control variables, only the effect of Morphological Regularity was significant, and thus this variable was taken into account in the main model constructed to examine the effects of Non-word Type and Language Group. Model comparisons revealed that the model including the interaction between Non-word Type and Language Group, in addition to the main effects of Non-Word Type, Language Group and Morphological Regularity as fixed factors, with Participants and Items as random factors, resulted in a better fit than the additive model including only the main effects χ^2 (2) = 40.61, $p < .001$. Allowing Morphological Regularity to interact with Language Group resulted in convergence failure.

Within this interactive model, the effect of Morphological Regularity (β = –.45, SE = .11, Z = –4.2, $p < .001$) was significant. In addition, the effect of Language Group was significant ($p < .001$), indicating that native Hebrew speakers responded more accurately (M = .99) than SA–LA–Hebrew speakers (M = .93). Finally, the two-way interaction between Non-word Type and Language Group was also significant (p = .03). In order to follow up on this two-way interaction, we analysed the effect of Non-word Type in each Language Group, using the Bonferroni adjustment. These analyses revealed that, in both groups, the effect of Non-word Type was not significant (all *P*'s *NS*) (see Figure 6).

3 Discussion

The results of Experiment 3 replicate the critical findings observed in Experiment 2, where the cross-lingual pseudo-homophone effect was facilitatory rather than inhibitory. In particular, SA–LA–Hebrew speakers responded more quickly to non-word Hebrew letter strings that sounded like a real word in their native language (SA) in comparison to non-words that did not sound like any real word.

Critically, both Experiments 2 and 3 demonstrate that in different-script bilinguals, cross-lingual pseudo-homophone facilitates rather than interferes with lexical-decision performance. We discuss possible interpretation of the difference between our findings and previous studies showing interference effects (e.g. Bentin and Ibrahim, 1996; Nas, 1983; Rubenstein et al., 1971) in Section V.

V General discussion

The aim of the present study was to investigate cross-lingual phonological effects during bilingual visual-word recognition in the absence of either orthographic or semantic overlap. To isolate cross-lingual phonological effects, we focused on SA–LA–Hebrew speakers, who are native speakers of SA and proficient readers of both LA and Hebrew. In particular, we investigated whether non-lexical orthographic representations (non-words) in one language (Arabic or Hebrew) activate phonological lexical representations in the

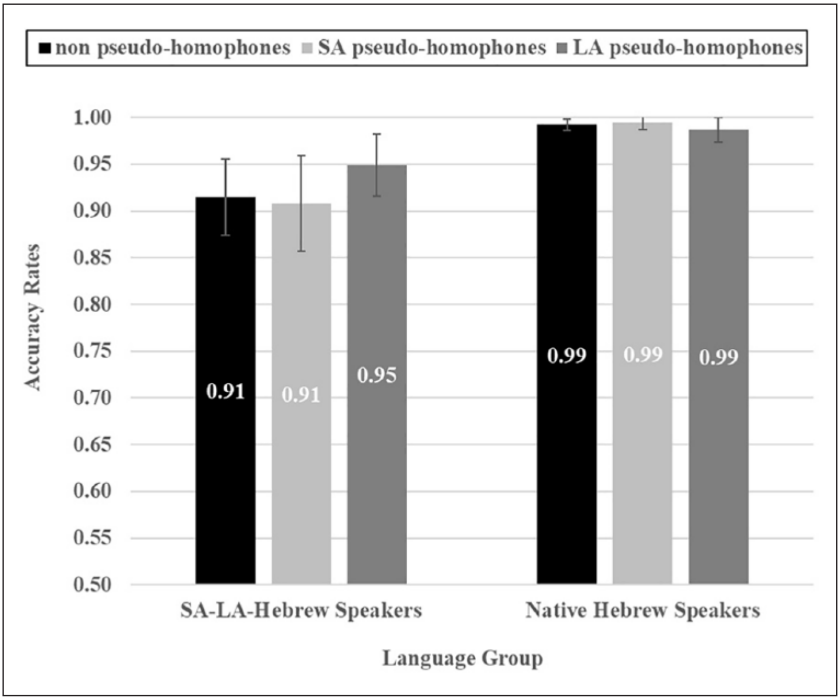

Figure 6. Accuracy on non-words as a function of language group and non-word type in a Hebrew lexical-decision task (Experiment 3).
Notes. Error bars represent the 95% confidence intervals. SA = Spoken Arabic; LA = Literary Arabic.

non-target language. Because non-words do not activate semantic representations, and because there is no orthographic overlap between SA, LA, and Hebrew, cross-lingual activation can only be mediated via phonological connections.

In three experiments, SA–LA–Hebrew speakers were asked to perform a lexical-decision task either in LA (Experiment 1) or in Hebrew (Experiments 2 and 3). The critical stimuli were non-words in the target language that either sounded like words in the non-target language (cross-lingual pseudo-homophones) or did not sound like a real word (non-pseudo-homophones). In Experiment 1, phonological effects were obtained across the two Arabic forms (LA and SA), but not between the two languages (LA and Hebrew). Specifically, LA non-words that sounded like SA words were more difficult to reject than LA non-words that did not sound like familiar words, whereas there was no significant difference between the latter condition and LA non-words that sounded like Hebrew words. In contrast to the LA experiment (Experiment 1), in the Hebrew Experiments (Experiments 2 and 3), cross-lingual phonological effects were obtained: In both experiments, Hebrew non-words that sounded like SA words were easier to reject than Hebrew non-words that did not sound like a real word (see Appendix 2).

In what follows, we discuss three major findings that emerge from these experiments. (1) evidence for pure cross-lingual phonological effects in bilingual visual-word recognition, even in the case of two languages (Arabic and Hebrew) that do not share the same script; (2) potential modulations of cross-lingual phonological effects at the word identification system, by language dominance; and (3) potential modulations of the cross-lingual phonological effects at the task decision system by the degree of similarity between the two languages in question.

First, the major finding of the present study is that cross-lingual pseudo-homophone effects can be obtained even between languages that do not share the same script (Arabic and Hebrew, Experiments 2 and 3). In particular, in the two Hebrew lexical-decision experiments, SA–LA–Hebrew speakers rejected SA pseudo-homophones more easily than non-pseudo-homophones, whereas Hebrew speakers, with no knowledge of Arabic, did not distinguish between the different non-word types. The fact that native Hebrew speakers with no knowledge of Arabic showed no difference between the different non-word types, provides strong evidence that the locus of the non-word type effect (observed with SA–LA–Hebrew speakers) cannot be reduced to orthographic markedness (van Kesteren et al., 2012), and can only be mediated via cross-lingual phonological activation. Moreover, to further overcome the confounding effect of orthographic factors, important stimuli characteristics – bigram frequency, trigram frequency, orthographic neighborhood size, and morphological regularity – were taken into account in the analyses of the results. Importantly, phonological effects (i.e. differences between non-word types), and more specifically the two-way interaction between Non-word Type (cross-lingual pseudo-homophones vs. non-pseudo-homophones) and Language Group (Arabic–Hebrew vs. Hebrew speakers with no knowledge of Arabic) remained significant even after these control variables were taken into account. Thus, consistent with interactive models of multilingual visual-word recognition (Dijkstra and van Heuven, 2002), the cross-lingual pseudo-homophone effects indicate that orthographic representations in one of the participants' languages (Hebrew) automatically and non-selectively activate phonological representations in the participants' other language (SA). Importantly, this cross-lingual phonological effect was obtained even between two languages with distinct orthographies (Arabic and Hebrew), thus extending previous studies with same-script bilinguals (e.g. Nas, 1983). Further, these findings are consistent with the notion proposed by the BIA+ model (Dijkstra and van Heuven, 2002), by which the multilingual system includes forward-only links from sub-lexical and lexical representations to the language nodes. Language membership representations likely receive activation from both lexical and sub-lexical orthographic representations in different script bilinguals (see Degani et al., 2018), but critically do not operate on the lexical identification system. As a result, despite clear orthographic cues to language membership, the current study provides strong evidence for cross-lingual phonological effects.

Second, cross-lingual phonological effects are non-symmetric, as cross-lingual pseudo-homophone effects were observed when participants (SA–LA–Hebrew speakers) were making a lexical-decision task in their L2 (Hebrew) but not in their L1 (Arabic). Specifically, in the LA lexical-decision task (Experiment 1), phonological effects were observed across the two Arabic forms (i.e. with L1 SA pseudo-homophones), but not when the pseudo-homophones corresponded to Hebrew (L2) words. In contrast, as mentioned above, in the Hebrew (L2) lexical-decision experiments, cross-lingual phonological effects were observed, as SA pseudo-homophones (Hebrew non-words that sound like real L1 SA words) were easier to reject than non-pseudo-homophones (Hebrew non-words that do not sound like real words). This asymmetry is consistent with previous studies showing stronger cross-lingual effects from the dominant L1 than from the less-dominant language (e.g. Gollan et al., 1997; for review, see Basnight-Brown and Altarriba, 2007).

Third, and most interestingly, the cross-lingual pseudo-homophone effect obtained in the present study (from Arabic to Hebrew) was facilitatory rather than inhibitory. That is, in contrast to the 'pseudo-homophone interference effect' reported in studies conducted with monolingual speakers (e.g. Rubenstein et al., 1971; van Orden, 1987; Ziegler et al., 2001), diglossic speakers (e.g. SA and LA, see Bentin and Ibrahim, 1996, as well as Experiment 1), and same-script bilinguals (Nas, 1983), the results of the current study, with different script bilinguals, demonstrate a 'pseudo-homophone facilitation effect'.

In particular, in the current study, SA pseudo-homophones were examined in both a within-language condition (in the LA lexical-decision experiment), and a between-language condition (in the Hebrew lexical-decision experiments). In accordance with previous findings (e.g. Bentin and Ibrahim, 1996; Nas, 1983; Rubenstein et al., 1971), a pseudo-homophone interference effect was observed in the within-language condition (i.e. involving the two forms of Arabic: SA and LA). Specifically, LA non-words that sounded like real words in SA were harder to reject compared to LA non-words that did not sound like real words. Interestingly, and in contrast to previous studies, in the between-language condition (i.e. involving Arabic and Hebrew), the effect was facilitatory rather than inhibitory. Specifically, Hebrew non-words that sounded like real words in Arabic (SA) were easier to reject than Hebrew non-words that did not sound like real words.

Critically, both the inhibitory effect in Experiment 1 and the facilitatory effect in Experiments 2 and 3 exemplify that the lexical phonological representation associated with the pseudo-homophone was indeed activated in the word identification system of the bilingual speaker. We interpret the different direction of the effect as the result of factors operating at the task-decision system, as outlined below.

According to the BIA+ model, the bilingual lexical system is organized into a word identification system driven by stimulus characteristics and a task-decision system, influenced by non-linguistic factors. The flow of information is unidirectional from the word identification system to the task-decision system. Recent support for this dissociation in the case of different-script multilinguals comes from Miwa et al. (2014), in which Japanese–English bilinguals completed a lexical-decision of cognates and non-cognates. Critically, they measured the time course of processing using eye tracking, distinguishing between initial automatic activation measurements (e.g. first-fixation), and later controlled decision processes (e.g. total time). Their findings support dissociation between these different phases in processing, as phonological overlap resulted in different patterns in the two types of measures.

We suggest that in our study, activation of SA pseudo-homophones resulted in either facilitatory or inhibitory effects depending on the operation of multiple factors at the task decision system. First, in all experiments only non-cognate items were included (see also Bentin and Ibrahim, 1996). This list composition makes it such that identification of a lexical candidate in the non-target language/form (SA) signals a non-word response in the target language/form (Hebrew or LA). Therefore, once a non-word is identified as a lexical representation in the non-target language/form, it may facilitate a 'no' decision relative to a non-word that does not correspond to any lexical representation in the system. Nevertheless, several factors may work together to influence the use of this cue at the decision system. First, the difference in proficiency in the target language influences the time course of the decision. Specifically, for SA–LA–Hebrew speakers, a decision in LA, may be faster than a decision in Hebrew. Indeed, as shown in Table 1, the time to make a 'no' response in LA appears to be faster than the time to make a 'no' response in Hebrew. It is possible therefore that in the Hebrew Experiments, SA words were activated before a decision was reached in Hebrew, facilitating a 'no' decision for SA pseudo-homophones relative to non-pseudo-homophones. In contrast, in Experiment 1, SA words were activated simultaneously with the 'no' decision in LA, creating competition at the decision level, yielding longer RTs for SA pseudo-homophones than for non- pseudo-homophones. Second, Hebrew and Arabic have distinct scripts and are therefore more distinguishable than two languages that share the same script (e.g. Dutch and English) or two forms of the same language (e.g. SA and LA). Thus, when Hebrew letter strings activate lexical representations in Arabic, these activations facilitate a 'no' response in a Hebrew lexical-decision task. In contrast, when LA letter strings activate SA words, it is more difficult to distinguish between these two forms, as both are considered Arabic. In other words, because SA is more similar to LA than to Hebrew (e.g. Saiegh-Haddad and Spolsky, 2014), SA–LA–Hebrew speakers are more likely to assume that an SA word is not a Hebrew word than they are to assume that it is not an LA word. This general tendency reflects the long-term experience of the speakers with their languages, and may override the particular list composition.

We therefore suggest that degree of similarity between the two languages in question may modulate the direction of the cross-lingual pseudo-homophone effect, such that, in the context of a lexical-decision task, similar languages (e.g. two languages that share the same script, like Dutch and English), will exhibit the typical pseudo-homophone interference effect, whereas languages that are more distinct (e.g. languages that have distinct scripts, like Arabic and Hebrew) will exhibit a facilitation effect. To further investigate this proposal, a similar study with Hebrew–English bilinguals is currently being done in our lab. Given that Hebrew and English are even more different than Hebrew and Arabic, a cross-lingual pseudo-homophone facilitation (rather than interference) effect is expected.

In summary, the results of the current study provide compelling evidence for pure phonological cross-lingual influences, which are independent of both orthographic and semantic overlap. These findings highlight the interconnectivity in the multilingual lexicon, both at the sub-lexical and the lexical levels. In addition, our results highlight the role of language dominance in modulating these cross-lingual influences, with an asymmetric pattern of more pronounced influence from the dominant to the less dominant language than the reverse. Finally, the degree of similarity between the two forms/languages in question appear to influence performance by operating at the task-decision system. Future research is needed in order to further explore the automatic aspects of these cross-lingual interactions in bilingual speakers and to shed light on the time course of these processes.

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Notes

1. It is important to note that although there is evidence that LA is processed like a second language (e.g. Eviatar and Ibrahim, 2001; Ibrahim, 2006, 2009; Ibrahim and Aharon-Peretz, 2005) Arabic native speakers do not consider the two varieties of their language as two different languages, rather as two forms of the same language (diglossia). Also, despite a remarkable distance between the two forms, as research has shown (Saiegh-Haddad and Spolsky, 2014), the two forms are related at all linguistic levels.
2. Note that in both LA and Hebrew, letters represent mostly consonants. Vowels can optionally be superimposed on consonants as diacritical marks (points). Thus, both languages have two forms of spelling: a voweled form which is orthographically transparent (i.e. phonologically unambiguous), and an unvoweled form which is more opaque (i.e. phonologically ambiguous). Most written materials (except for poetry, literature for children, and religious texts) use the unvoweled form. Nevertheless, given our focus on sub-lexical orthographic-phonological connections the letter strings in both the LA and the Hebrew experiments were presented with phonemic diacritics, in order to convey full phonological information (for a comprehensive review of vowels in Semitic languages, see Ibrahim, 2010; Saiegh-Haddad and Henkin-Roitfarb, 2014; Saiegh-Haddad and Schiff, 2016).
3. This control group was included in order to ensure that cross-lingual effects, if obtained, are indeed a result of our phonological manipulation (SA pseudo-homophones vs. non-pseudo-homophones) and not due to other uncontrolled stimuli characteristics. Thus, we expected only the SA–LA–Hebrew group (but not the native Hebrew control group) to be sensitive to the difference between these two types of Hebrew non-words. Such a control group was not possible in Experiment 1 given that all Arabic readers of LA are also proficient in SA. In addition, all Arabic speakers in Israel are exposed to Hebrew.

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Appendix 1

Experimental stimuli.

Experiment 1. A. Spoken Arabic (SA) pseudo-homophones: Non-words in Literary Arabic (LA) that sound like real words in SA.

LA print	IPA	OrthN	MorR (0–2)	Meaning	Subjective familiarity (1–7 scale)	Length (number of letters)	Mean bigram frequency	Mean trigram frequency
بُرِدَاي	burdaj	67	2	curtain	6.3	5	0.00050635	0.00000222
سَفرطَاس	s`eferta:s`	2	0	box	6	6	0.00029921	0.00001362
جنينِه	ʤneni	54	2	garden	6.6	5	0.00244460	0.00012180
ثِم	θem	31	1	mouth	7	2	0.00046430	n/a
تَطلِي	t`et`li	64	1	jam	6.7	4	0.00224071	0.00005880
شَاكُوش	ʃakuʃ	20	1	hammer	6.5	5	0.00032003	0.00000340
نَطّة	nat`t`e	58	1	jump	6.2	3	0.00038207	0.00000128
طَرّاش	t`arraʃ	24	1	painter	5.3	4	0.00027169	0.00000330
أُوضَه	ʔʊd`e	51	1	room	6	4	0.00021904	0.00001924
قَبظَة	qebð`e	26	1	salary	5.5	4	0.00026841	0.00000002
خُرّافِيّة	xurafeji	39	2	story	6	6	0.00330286	0.00007646
شَقفِه	ʃaqfı	40	1	piece	6	4	0.00023802	0.00000530
بِروَاز	birwaz	50	1	picture frame	5.7	5	0.00075336	0.00001972
خُوصَة	xʊ:s`a	32	2	knife	6	4	0.00034751	0.00000203
مَصَارِي	mes`ari:	59	1	money	6.8	5	0.00131592	0.00006651
صُوبَا	s`ʊbba	52	1	heater	5.4	4	0.00058725	0.00000245
شَرشَف	ʃarʃef	18	1	tablecloth	6	4	0.00055451	0.00000024
طُوس	ʈ`u:ʂ`	32	1	garbage can	5.4	3	0.00087551	0.00000026
هِسهِسِه	heshesi	1	0	mosquito	6.6	5	0.00020691	0.00000002
قُرنِة	qurni	66	2	corner	6.9	4	0.00073360	0.00003563

Note. OrthN = size of orthographic neighborhood. MorR = morphological regularity (0 = a letter string with no familiar root and no familiar word pattern; 1 = a letter string with either a familiar root or a familiar word pattern; 2 = a letter string with both a familiar root and a familiar word pattern).

B. Hebrew pseudo-homophones: Non-words in Literary Arabic (LA) that sound like real words in Hebrew.

LA print	IPA	OrthN	MorR (0–2)	Meaning	Subjective familiarity (1–7 scale)	Length (number of letters)	Mean bigram frequency	Mean trigram frequency
سِيعَار	seʕar	78	1	hair	7	5	0.00080602	0.00006743
ياعار	jɑʕer	18	1	forest	5.8	5	0.00000467	0.00006327
كِير	kɪːr	59	1	wall	6.6	3	0.00205410	0.00004949
اوزن	ʔʊzɪn	49	1	ear	7	4	0.00026112	0.00001002
شَاعُون	ʃaʕʊːn	34	1	watch	6.7	5	0.00084511	0.00002753
تِينُوك	ʈinuːk	62	1	baby	7	5	0.00206007	0.00007163
ترُوفَا	trufa	85	1	drug	6.5	5	0.00100739	0.00005392
عِيشُون	ʕɪʃʊn	31	1	smoking	6	5	0.00116182	0.00002604
اُولَام	ʔʊlaːɱ	44	2	hall	7	4	0.00121371	0.00000186
إكدَاح	ʔikdax	2	2	gun	6.5	5	0.00004976	0.00000103
شَالُوم	ʃelʊːm	36	1	peace	7	5	0.00120910	0.00006214
حَاتُول	xatul	48	1	cat	6.5	5	0.00151108	0.00005446
شوعال	ʃuʕal	12	2	fox	6.5	5	0.00040976	0.00004084
حِيمئا	ximʔa	1	1	butter	6.3	5	0.00085477	0.00000644
عِيسِك	ʕəsək	48	1	business	6.8	4	0.00094772	0.00001289
كِركَاس	kirkas	25	1	circus	5.6	5	0.00068948	0.00006562
لَشُون	ləʃʊːn	71	1	tongue	6.2	4	0.00144456	0.00005231
كِيمَاح	kemax	40	1	flour	5.4	5	0.00069885	0.00012253
حالوك	xaluk	97	1	robe	6	5	0.00077450	0.00002264
بُوكِر	buker	62	1	morning	6.6	4	0.00088660	0.00001106

Note. OrthN = size of orthographic neighborhood. MorR = morphological regularity (0 = a letter string with no familiar root and no familiar word pattern; 1 = a letter string with either a familiar root or a familiar word pattern; 2 = a letter string with both a familiar root and a familiar word pattern).

C. Literary Arabic (LA) non-words that do not sound like familiar words.

LA print	IPA	OrthN	MorR (0–2)	Length (number of letters)	Mean bigram frequency	Mean trigram frequency
سَكاغِر	səkaːɣir	13	1	5	0.00015094	0.00002062
صَلاَف	s`əllaf	37	1	3	0.00040827	0.00000296
فَبِع	febiʕ	49	1	3	0.00080848	0.00000690
ذُسَاب	ðʊsaːb	14	1	4	0.00000641	0.00000015
ثرفِك	θerfik	40	1	4	0.00048404	0.00000046
زَمغَة	zemɣe	14	1	4	0.00015165	0.00000021
حَفق	ħefek	41	1	3	0.00044376	0.00000000
كَازِل	kazil	52	1	4	0.00004641	0.00000068
نَعُبَم	nuʕibem	34	0	4	0.00065200	0.00000127
حِوَتن	ħɪwetin	48	0	4	0.00101448	0.00004423
دِذَاء	diðaʔ	11	1	4	0.00000020	0.00000677
عَسَام	ʕesaːm	38	1	4	0.00004763	0.00000098

Experiment 1. (Continued)

LA print	IPA	OrthN	MorR (0–2)	Length (number of letters)	Mean bigram frequency	Mean trigram frequency
مَرفِحِية	merfiħji	26	1	6	0.00227045	0.00005703
ثُرفَة	terfe	37	1	4	0.00064880	0.00005647
دِكاغ	dika:ɣ	12	1	4	0.00004695	0.00000125
قُنلة	qunle	39	1	4	0.00058280	0.00000006
وِبَادة	wibade	100	1	5	0.00065474	0.00016039
كُوَابِش	kawabiʃ	27	1	5	0.00034646	0.00000064
كَوثب	kaueteb	30	1	4	0.00042251	0.00000353
قَذِيتَة	qaðiṱe	27	1	5	0.00061324	0.00000261
إشِسف	ʔɪʃsɪf	1	1	4	0.00006086	0.00000001
نُوجَث	nuʤiθ	12	1	4	0.00046976	0.00000068
حَباح	ħeba:ħ	24	1	4	0.00011590	0.00001019
فَعرش	feʕriʃ	52	1	4	0.00075640	0.00000168
فَربطة	feribt`e	59	1	5	0.00087589	0.00001998
خَكَله	xekle	28	1	4	0.00150925	0.00003429
ظَائِسَة	ða:ʔiʂe	3	1	5	0.00012177	0.00000582
ثَيلَرج	θilerʤ	1	0	5	0.00098876	0.00003347
فُمير	fumi:r	76	1	4	0.00197810	0.00012655
ذَسَات	ðesa:t	9	1	4	0.00001048	0.00000171
فَرسَعة	ferseʕe	34	1	5	0.00094433	0.00001908
بِلَسغ	bilesɣ	13	0	4	0.00123214	0.00000266
طِعَارة	t`iʕa:re	26	1	5	0.00068604	0.00028951
دَخيق	dexi:k	2	1	4	0.00073998	0.00000272
حِسَاج	ħisa:ʤ	22	1	4	0.00012971	0.00003534
نافِصَة	na:fise	36	1	5	0.00011857	0.00005207
مُحَفَع	muħfeʕ	6	1	4	0.00064594	0.00000540
كُفبِنل	kufbinel	22	0	5	0.00039417	0.00000020
فِمرث	fimriθ	45	1	4	0.00071679	0.00000153
مضشقر	med`eʃker	0	1	5	0.00028474	0.00000041

Note. OrthN = size of orthographic neighborhood. MorR = morphological regularity (0 = a letter string with no familiar root and no familiar word pattern; 1 = a letter string with either a familiar root or a familiar word pattern; 2 = a letter string with both a familiar root and a familiar word pattern).

Experiment 2. A. Spoken Arabic (SA) pseudo-homophones: Non-words in Hebrew that sound like real words in SA.

Hebrew print	IPA	Meaning	OrthN	MorR (0–2)	Subjective familiarity (1–7 scale)	Length (number of letters)	Mean bigram frequency	Mean trigram frequency
מָטְבּוּשׁ	matbuʃ	broken	5	1	7	5	0.00184021	0.00007268
כּוּזוֹק	xuzok	hole	0	0	6.7	5	0.00174468	0.00003438
עוּטוֹר	ɕutor	perfume	4	1	7	5	0.00328774	0.00019214
כָּרְבָּאן	xarban	rotten	5	0	6.3	5	0.00148995	0.00001828

(Continued)

Experiment 2. (Continued)

Hebrew print	IPA	Meaning	OrthN	MorR (0–2)	Subjective familiarity (1–7 scale)	Length (number of letters)	Mean bigram frequency	Mean trigram frequency
נִתְפֶּה	nitfe	little bit	40	1	6.6	4	0.00089288	0.00001694
זָעְלַאן	zaʕlan	sad	0	0	6.9	5	0.00241350	0.00002589
טָקִיֶּה	takije	hat	7	0	7	5	0.00345259	0.00038861
בָּרָנְדָה	baranda	balcony	6	0	6.2	5	0.00176183	0.00003065
חָפָאיֶה	ħafaje	flip flop	9	0	7	5	0.00255138	0.00002900
קוּנְדָרָה	kondara	shoe	5	1	7	6	0.00236049	0.00013071
בָּשְׁקִיר	baʃkir	towel	0	2	7	5	0.00242648	0.00011753
מְכָרְבָּט	mxarbat	confused	2	0	6.7	5	0.00110905	0.00004257
סוּכוּן	suxun	hot	18	1	7	5	0.00271698	0.00020889
אִסְתָחָא	ʔistaħa	ashamed	2	0	6.6	5	0.00055929	0.00000331
זָהְרִי	zahri	pink	27	1	7	4	0.00342818	0.00013603
בִּלְזָמֶש	belzameʃ	extra	0	0	6.8	5	0.00159434	0.00000488
אָוָאעִי	ʔawaʢi	clothes	1	0	7	5	0.00272890	0.00000331
זָראפֶה	zarafe	giraffe	2	0	7	5	0.00142891	0.00000547
אִנְמָחָא	inmaħa	deleted	0	0	7	5	0.00078779	0.00001714
זָלָמֶה	zalame	man	17	0	7	4	0.00167178	0.00006516
כָּמָאן	kaman	more	19	0	6.8	4	0.00123515	0.00002351
יִמְקֶן	jimken	maybe	26	1	5.5	4	0.00122026	0.00001243
סָקְעָה	sakʢa	cold	13	1	7	4	0.00064662	0.00001888
קָרְקָעָה	karkaʢa	noise	17	1	6.8	5	0.00105815	0.00008987
כוּרָאף	xurraf	talk	6	0	6	5	0.00339603	0.00012776
זָרֶף	zaref	bag	27	1	6.2	3	0.00070191	0.00000002
מִחְרָמֶה	miħrame	handkerchief	13	1	6.8	5	0.00179184	0.00006512
מָקְחוּט	makħut	scratched	0	1	7	5	0.00150691	0.00001288
טוּשוּט	tuʃot	bowl	1	0	6	5	0.00216867	0.00007834
מְפָעְפָש	mfaʢfaʃ	messy	2	0	6	5	0.00071633	0.00005827
בּוֹסֶה	bose	kiss	35	1	6.3	4	0.00221201	0.00006064
מְפָרְפֶש	mfarfeʃ	happy	2	1	6.8	5	0.00118744	0.00006760
זָאקִי	zaki	tasty	12	0	6.3	4	0.00113032	0.00007841
טאוְלֶה	tawle	table	8	0	7	5	0.00406515	0.00041337
כָרוּף	xaruf	sheep	24	1	6.3	4	0.00315221	0.00025355
עִיד	ʢid	holiday	27	1	6.3	3	0.00288607	0.00014727
מוּחָאמִי	muħami	judge	8	0	6.3	6	0.00295271	0.00007753
חָסָאס	ħasas	sensitive	1	0	5.4	4	0.00034557	0.00000134
קָמִיס	kamis	shirt	19	1	5.6	4	0.00221107	0.00002526
בָּטָּה	batta	duck	29	1	7	3	0.00053296	0.00000655
מָזְבּוּט	mazbut	right	0	1	7	5	0.00143064	0.00003537
בָּאיֶךְ	bayex	repulsive	13	0	6.3	4	0.00283337	0.00026968
סוּמְעָה	sumʢa	rumor	15	1	6.8	5	0.00203085	0.00004294
סָאעָה	saʢa	clock	8	0	7	4	0.00037870	0.00000015
מִסְטָרָה	Mistara	ruler	20	2	7	5	0.00148078	0.00015310

Experiment 2. (Continued)

Hebrew print	IPA	Meaning	OrthN	MorR (0–2)	Subjective familiarity (1–7 scale)	Length (number of letters)	Mean bigram frequency	Mean trigram frequency
מְכָדֶה	emxade	cushion	25	1	6.2	4	0.00099406	0.00000448
מִקְנְסֶה	mikense	broom	13	1	7	5	0.00078055	0.00005149
בָּאב	bab	door	16	0	7	3	0.00154798	0.00002420
שוּבָּאק	shubak	window	2	0	7	5	0.00255242	0.00020011
קָלָם	kalam	pen	36	1	7	3	0.00152921	0.00000404

Note. OrthN = size of orthographic neighborhood. MorR = morphological regularity (0 = a letter string with no familiar root and no familiar word pattern; 1 = a letter string with either a familiar root or a familiar word pattern; 2 = a letter string with both a familiar root and a familiar word pattern).

B. Hebrew non-words that do not sound like familiar words.

Hebrew print	IPA	OrthN	MorR (0–2)	Length (number of letters)	Mean bigram frequency	Mean trigram frequency
פַּזְחָם	pazħam	10	0	4	0.00023638	0.00000037
צַקְלָם	tsaklam	8	0	4	0.00103282	0.00000211
פַּחְשָׁן	paħʃan	19	1	4	0.00105503	0.00000028
קַדְרָן	kadran	30	2	4	0.00078408	0.00001474
נִקְלָם	niklam	40	0	4	0.00125093	0.00001897
שַׁקְמָר	ʃakmar	19	1	4	0.00120164	0.00000472
רַשְׁלָם	raʃlam	18	1	4	0.00349332	0.00006977
קַרְמָד	karmad	11	1	4	0.00155242	0.00000979
לַחְבָּן	laħban	17	1	4	0.00129354	0.00004387
גַּלְבָּד	galbad	3	1	4	0.00110614	0.00009795
בַּחְלָץ	baħlats	11	1	4	0.00097216	0.00002934
פַּעְקָשׁ	paςkaʃ	0	1	4	0.00072771	0.00000518
לַחְדָן	laħdan	13	1	4	0.00091980	0.00001721
צַמְעָם	tsamςam	19	0	4	0.00107036	0.00005480
הִתְפָּמֶז	hitpamez	2	1	4	0.00102424	0.00008066
מִסְגֶבֶת	misgevet	12	1	4	0.00104961	0.00004891
מְקָחְשֶׁם	mkaħʃem	8	0	5	0.00093916	0.00001912
בַּחֶקֶת	baħeket	17	1	5	0.00076196	0.00002044
צַמֶקֶת	tsameket	25	2	4	0.00076256	0.00000271
פַּחְקָם	paħkam	18	0	4	0.00046068	0.00000006
צַבֶקֶת	tsaveket	22	1	4	0.00069741	0.00000337
מְבָּכְרָשׁ	mbaxraʃ	12	0	4	0.00084220	0.00000761
בַּרְכָאן	barxan	6	1	4	0.00195039	0.00001940
עַלְזָאן	ςalzan	2	1	5	0.00154004	0.00000378
דָרָנְבָּה	daranba	5	0	5	0.00105160	0.00001430
קַשְׁבִּיר	kaʃbir	0	1	5	0.00371520	0.00031627
מָלָזָה	malaza	19	0	5	0.00082745	0.00001217

(Continued)

Experiment 2. (Continued)

Hebrew print	IPA	OrthN	MorR (0–2)	Length (number of letters)	Mean bigram frequency	Mean trigram frequency
רַקְעָק	rakçak	9	1	5	0.00051863	0.00007299
עָיָאפֶה	çajafe	8	0	4	0.00167348	0.00000970
קָחְמוּט	kaħmut	1	0	4	0.00184007	0.00007324
חָמְחוּן	ħamħun	2	0	5	0.00249040	0.00011760
מְרָפְמֶש	mraʃmeʃ	4	0	5	0.00182275	0.00000746
מְחַמְקֶש	mħamkeʃ	2	0	5	0.00107945	0.00001881
קָרְבָּס	karbas	10	1	5	0.00156928	0.00009778
שָקְמִיר	ʃakmir	12	1	4	0.00272811	0.00010385
חָרְמָר	ħarmar	13	1	5	0.00188446	0.00000812
לְזָמְבֶּש	lazambeʃ	0	0	4	0.00071625	0.00000862
רָעְבֶּפֶש	rabifeʃ	0	0	5	0.00071494	0.00000755
פָּרוּך	parux	41	0	5	0.00358597	0.00026201
רָבָּנְדָה	ɣabanda	7	0	5	0.00131290	0.00003312
טוּחוֹק	tuħuk	0	0	4	0.00238246	0.00028426
עָקְרָק	çakrak	10	1	5	0.00110585	0.00006807
זוּכוֹק	zuxuk	1	0	5	0.00197663	0.00004537
וָאטְלֶה	watle	1	0	5	0.00227606	0.00002490
לוּשאח	luʃaħ	8	0	4	0.00255703	0.00019800
צָרְגָן	ʦargn	10	0	5	0.00085619	0.00003993
צַלְקָן	ʦalkan	19	2	5	0.00067639	0.00001385
בָּחֶצֶת	baħetʦet	13	1	5	0.00052835	0.00001485
קָלְעָמֶה	kalçama	4	1	5	0.00133455	0.00003957
צָלְפָק	ʦalfak	8	1	4	0.00083092	0.00001100

Note. OrthN = size of orthographic neighborhood. MorR = morphological regularity (0 = a letter string with no familiar root and no familiar word pattern; 1 = a letter string with either a familiar root or a familiar word pattern; 2 = a letter string with both a familiar root and a familiar word pattern).

Experiment 3. A. Spoken Arabic (SA) pseudo-homophones: Non-words in Hebrew that sound like real words in SA.

Hebrew print	IPA	Meaning	OrthN	MorR (0–2)	Subjective familiarity (1–7 scale)	Length (number of letters)	Mean bigram frequency	Mean trigram frequency
טָאבִּי	tabi	ball	16	0	7	4	0.002792267	0.0002013891
מָסַארִי	masari	money	21	0	7	5	0.002686175	0.0000841132
תֲכִית	tæħət	bed	30	1	7	4	0.003127245	0.0000244067
לֲמְבָּה	lamba	lamp	16	1	6.7	4	0.001711263	0.0000157770
בּוֹת	bot	shoe	25	1	6.6	3	0.009602845	0.0009425044
מְכָאדִי	mxæde	pillow	10	0	6.7	5	0.001826577	0.0000293017
בִּסֵה	bise	cat	30	1	6.5	3	0.000534916	0.0000026429
בּוּדְרָה	budra	powder	33	2	5.3	5	0.002931648	0.0002196519
תּוֹשְט	toʃt	bowl	26	0	6	4	0.002115124	0.0001001085

Experiment 3. (Continued)

Hebrew print	IPA	Meaning	OrthN	MorR (0–2)	Subjective familiarity (1–7 scale)	Length (number of letters)	Mean bigram frequency	Mean trigram frequency
אָדַּאחָה	adæħæ	lighter	1	0	5.7	5	0.000869934	0.0000029034
אֶרְמָא	ʔærma	sign	11	0	6	4	0.00148594	0.0000242113
שָׁאקוּש	ʃækuʃ	hammer	0	0	6.8	5	0.001853488	0.0000305351
לַפְחָה	læfħæ	scarf	18	1	5.4	4	0.000737942	0.0000655095
שׁוֹרְבָּה	ʃoraba	soup	28	1	6	5	0.003554432	0.0002745016
אשָׁאט	ʔʃat	belt	16	0	5.4	4	0.001078301	0.0000037805
שָׁנְטָה	ʃænta	bag	28	1	6.6	4	0.001047371	0.0000130307
בּוּרְדָאי	burdaj	curtain	1	0	6.9	6	0.003421008	0.0002348907
שָׁמְסִיֵּה	ʃæmsijə	umbrella	8	0	6.5	5	0.00265229	0.0000888934
קָבּוּת	kabut	coat	27	1	6.8	4	0.006760301	0.0007075850
חַרָאמִי	ħarami	thief	7	0	5.7	5	0.003095642	0.0000881503

Note. OrthN = size of orthographic neighborhood. MorR = morphological regularity (0 = a letter string with no familiar root and no familiar word pattern; 1 = a letter string with either a familiar root or a familiar word pattern; 2 = a letter string with both a familiar root and a familiar word pattern).

B. Literary Arabic (LA) pseudo-homophones: Non-words in Hebrew that sound like real words in LA.

Hebrew print	IPA	Meaning	OrthN	MorR (0–2)	Subjective familiarity (1–7 scale)	Length (number of letters)	Mean bigram frequency	Mean trigram frequency
מִסְעָד*	misʕad	elevator	23	2	6.9	4	0.001051129	0.0000435390
פִּנָאא	fina	courtyard	7	0	6.2	4	0.000575649	0.0000021029
סָחִיפָה*	sħifa	newspaper	22	1	7	5	0.001273935	0.0001370402
שָׁאחֵן	ʃaħen	charger	13	0	6.8	4	0.001169519	0.0000230737
חוּקְנָה	ħukna	injection	36	1	6.2	5	0.002345022	0.0001721869
מָלַאבֶּס	malabes	clothes	1	0	7	5	0.001708788	0.0000721014
סוּבָּאת	subat	sleep (n)	26	0	6.5	5	0.003189224	0.0001223701
חָלָאקָה	ħalake	ring	3	0	6.5	5	0.001666675	0.0000045044
שָׁאטֵא	ʃate	beach	1	0	6.8	4	0.000573766	0.0000072738
קוּבְּלָה	kubla	kiss	31	2	6.6	5	0.003628165	0.0001845664
רוּחָאם	ruħam	marble	17	1	6.2	5	0.002357897	0.0000721168
מוּקָיֵף	mukajef	air-conditioner	14	0	7	5	0.002646805	0.0001826130
מָלְהָא	malha	nightclub	11	0	5.8	4	0.003082097	0.0000497210
מוּדָרֵס	mudares	teacher	12	1	7	5	0.002938678	0.0002002400
שוּרְפָה	ʃurfa	balcony	42	2	6	5	0.002853703	0.0001490596
קָפְזָה	kafza	jump	9	1	6.2	4	0.000570198	0.0000008503
נִפָאיָה	nifaja	trash	10	0	6.8	5	0.002661513	0.0000301750
טָאהִי	tahi	cook (n)	1	0	5.4	4	0.001941196	0.0000064349
כּוּבּ	kub	cup	28	1	6	3	0.00351014	0.0000430678
קְנֵינִי	knejni	bottle	16	0	6.9	5	0.005146517	0.0004612513

Notes. * items that were excluded from analyses due to low accuracy; see text for details. OrthN = size of orthographic neighborhood. MorR = morphological regularity (0 = a letter string with no familiar root and no familiar word pattern; 1 = a letter string with either a familiar root or a familiar word pattern; 2 = a letter string with both a familiar root and a familiar word pattern).

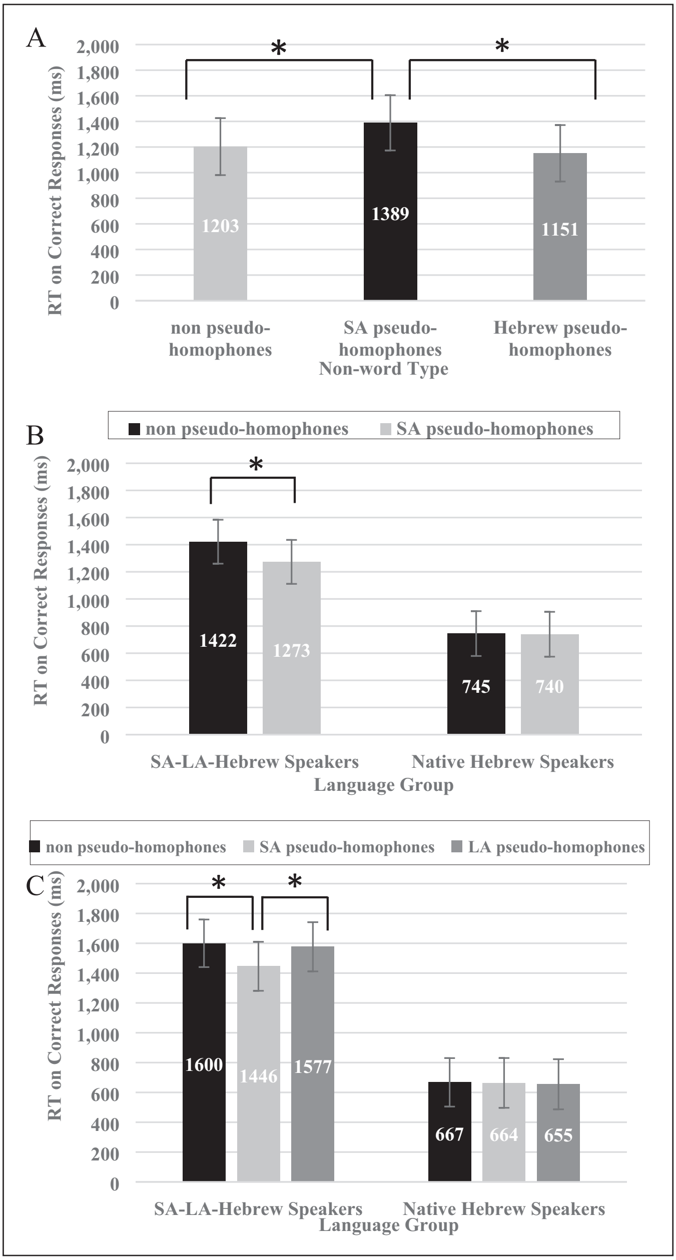
C. Hebrew non-words that do not sound like familiar words.

Hebrew print	IPA	OrthN	MorR (0–2)	Length (number of letters)	Mean bigram frequency	Mean trigram frequency
אֲחַאדָה	ʔaħada	2	0	5	0.000992119	0.0000186918
אֲרְהָם	ʔarham	27	0	4	0.001837062	0.0000323928
קָאשׁוּשׁ	kaʃoʃ	1	0	5	0.002075105	0.0001775263
לָחְפָה	laħfa	25	1	4	0.000671332	0.0000086641
שׁוּבְרָה	ʃubra	44	2	5	0.003697834	0.0004592672
אִטָאשׁ	ʔitaʃ	4	0	4	0.000730628	0.0000049296
טֲשְׁנָה	taʃna	20	1	4	0.001771772	0.0002338623
שָׁסְמִיָה	ʃasmija	11	0	5	0.002537424	0.0000510041
קוּבָּת	kubat	30	1	4	0.003012101	0.0001786831
סוּבִּי	subi	42	2	4	0.004390528	0.0004310457
מֲרַאחִי	marʔaħi	13	0	5	0.002742333	0.0000563819
בָּאטִי	bati	19	0	4	0.001601014	0.0000265899
אָעַאוִי	ʔaçavi	1	0	5	0.001947895	0.0000381267
בָּזַאלִי	bazʔali	1	0	5	0.002768743	0.0002980809
אֲרְנָדַב	arnadav	2	0	5	0.000907808	0.0000372381
מֲרָאסִי	marʔasi	12	0	5	0.002290758	0.0000731049
תּוּבּ	tub	22	1	3	0.003692747	0.0001048657
סִהֵב	siheb	15	1	3	0.001123891	0.0000000460
רוּדְבָּה	rudba	15	1	5	0.00330066	0.0000190442
שִׁתֵּד	ʃited	20	1	3	0.000734168	0.0000014019
אָלוּעָה	ʔaloça	8	1	5	0.002967152	0.0001431380
אִיחוּשׁ	ʔiħuʃ	12	1	5	0.003090161	0.0001826972
אֲחְסַא	ʔaħsa	8	0	4	0.000920486	0.0000025395
בְּחִיקָה	bħika	13	1	5	0.001838856	0.0002938829
תִּיסָאר	tisʔar	20	0	5	0.001720285	0.0000132222
הִילְזָם	hilzam	5	0	5	0.001953617	0.0000576689
טִימְעָף	timçaf	1	0	5	0.001571483	0.0000305083
לוּבְּקָה	lubka	12	1	5	0.00257724	0.0000685852
קָארֵס	kares	10	1	4	0.001071417	0.0000468598
רוּכָּא	ruxa	19	0	4	0.002972663	0.0000803902
מְבַאלֵס	mvʔales	0	0	5	0.001696576	0.0000314773
פִּנָאיָה	pinʔaja	21	0	5	0.002863949	0.0001235652
פּוּשְׁרָה	puʃra	42	2	5	0.002645639	0.0000954585
נוּדוּק	nuduk	8	0	5	0.003609544	0.0001390702
רֲסִיר	rasir	8	1	4	0.002851684	0.0001643769
רָאוֹן	raʔon	23	1	4	0.003907423	0.0001776145
תָּפְכּוֹר	tafxor	29	1	5	0.002587415	0.0000743843
פוּגְיָה	fugija	26	1	5	0.002599765	0.0001472824
גוּעְיָה	guçija	30	1	5	0.0031574	0.0001716506
לִמְשָׁה	limʃa	26	1	4	0.003056081	0.0001951610

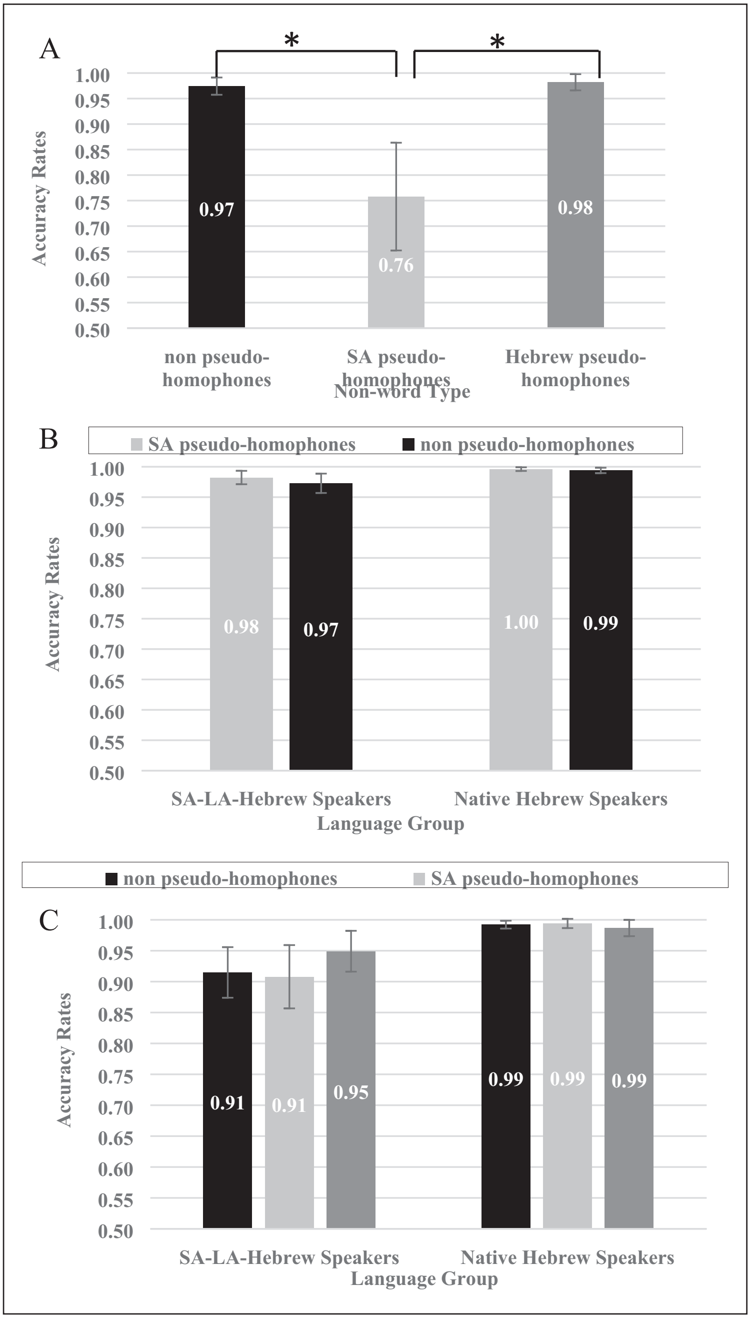
Note. OrthN = size of orthographic neighborhood. MorR = morphological regularity (0 = a letter string with no familiar root and no familiar word pattern; 1 = a letter string with either a familiar root or a familiar word pattern; 2 = a letter string with both a familiar root and a familiar word pattern).

Appendix 2.

Reaction time (RT) data and Accuracy data.



Appendix 2a. Reaction time (RT) data: Top panel (A) = Experiment 1; middle panel (B) = Experiment 2, and bottom panel (C) = Experiment 3.



Appendix 2b. Accuracy data: Top panel (A) = Experiment 1; middle panel (B) = Experiment 2, and bottom panel (C) = Experiment 3.