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Bilingual phonological awareness as a function of language proficiency

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Abstract

Aims and objectives: The present study examined whether phonological awareness reflects a stable construct or whether it varies by the different languages of bilingual speakers. In particular, the study tests to what extent language proficiency determines phonological awareness above and beyond language structural characteristics.
Methodology: Bilingual adult speakers were tested as they afford within-participant comparisons to address this issue. Specifically, 29 Hebrew (L1)-English (L2) bilinguals were compared to 33 English (L1)-Hebrew (L2) bilinguals on a timed auditory rhyme judgment task including 270 word-pairs (90 English pairs, 90 Hebrew pairs, and 90 pseudo-Hebrew pairs).
Data and analysis: Reaction times and *d′* on the rhyme judgment task were compared between the two bilingual groups to examine the role of language proficiency in predicting phonological awareness performance. Furthermore, rhyme judgments on Hebrew pairs were correlated with those on English pairs to provide within-participant index of phonological awareness stability.
Findings: Rhyme judgment performance on the same set of words was affected by the strength of linguistic representations, as determined by language proficiency profile. English-Hebrew bilinguals performed better on English pairs, whereas Hebrew-English bilinguals performed better on Hebrew pairs. Moreover, within-group comparisons revealed that performance in the more proficient language was not correlated with performance in the less proficient language.
Originality: By testing two groups of bilinguals who differ in their language dominance profile using the same set of materials (including both L1 and L2 pairs), the results reveal differences in phonological awareness abilities as a function of language proficiency that cannot be reduced to structural differences between the examined languages.
Significance: The findings underscore the dynamic nature of phonological awareness abilities and carry implications for clinical diagnosis of bilingual populations, in that rhyme judgment performance in one language should not be taken to index expected abilities in the other language of bilingual speakers.

Keywords
Phonological awareness, rhyme judgment, bilingualism, language proficiency, strength of linguistic representations

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An important aspect of cognitive ability is the individuals' awareness of the sound components that combine to create words. This *phonological awareness* allows decoding of the word's sound components, supporting comprehension as well as production and fluent retrieval (James & Burke, 2000; Moriarty & Gillon, 2006; Saiegh-Haddad, 2019). Moreover, phonological awareness has been shown to be important for reading and writing acquisition (Fowler, 1991; Saiegh-Haddad & Geva, 2008; Vellutino & Scanlon, 1987; Walley et al., 2003). Specifically, different components of phonological awareness abilities at preschool are linked to reading proficiency later on (for review, see Brady & Shankweiler, 1991), and reading difficulties have been suggested to stem from low ability to manipulate the phonological structure of the language at the spoken level (De Jong & Van der Leij, 2003; Russak & Saiegh-Haddad, 2011; Saiegh-Haddad, 2019). However, despite its prominent role in language research, it is still unclear to what extent phonological awareness is a constant ability, such that a single valid measure is sufficient to predict future performance across multiple contexts, or whether this is a dynamic skill that is dependent on the strength and/or availability of the representations over which it is computed. In the current study, this issue is examined in the context of bilingual speakers. Specifically, we ask whether bilinguals' phonological awareness is the same in both the first (L1) and the second language (L2).

In the case of bilingual speakers, phonological awareness may be viewed as a *single entity*, such that it is independent of the language in question. Such language independent view sees metaphonological skills as part of one's general cognitive resources operating independently of linguistic representations. Phonological awareness can therefore be seen as constrained by working memory limitations (Leather & Henry, 1994; Oakhill & Kyle, 2000; Rohl & Pratt, 1995) or as tightly linked to auditory perception (e.g., Janssen et al., 2017). Notably, the single entity view would predict that bilinguals' phonological awareness will be highly correlated between their two languages, because once this metalinguistic ability develops in one language it can be applied to other languages as well (Durgunoğlu et al., 1993). Indeed, there is evidence to suggest that children's phonological awareness in their L1 is predictive of their phonological awareness performance in their L2 (Bialystok et al., 2005; Durgunoğlu et al., 1993).

In contrast, other theories pose that phonological awareness is not only a domain-general construct, but rather encompasses a linguistic component as well (e.g., the Linguistic Affiliation Hypothesis, Russak & Saiegh-Haddad, 2011, 2017; Saiegh-Haddad, 2007b). By this alternative, phonological awareness abilities depend on the strength and availability of linguistic representations, specifically the phonological representations in long-term memory (for a discussion, see Saiegh-Haddad, 2019). Under such a theoretical view, phonological awareness may be composed of multiple entities such that it may change by language (Russak & Saiegh-Haddad, 2011; Saiegh-Haddad, 2019). These language-dependent, or specific, approaches imply that phonological awareness in one language *is not* sufficient to explain phonological awareness performance in the other language. This is not to say that there are no domain-general components to phonological awareness that are independent of language, but rather that at least some components change by language.

The multiple-entity view of phonological awareness

To the extent that phonological awareness compromises multiple entities, one may expect divergence in bilinguals' phonological awareness performance in their two languages. In support of this suggestion, Branum-Martin et al. (2006) exemplified statistical separability of English and Spanish phonological awareness measures among a large sample of English-Spanish bilingual children (although considerable overlap was also documented). Similarly, Saiegh-Haddad and Geva (2008) observed differential performance in a phoneme deletion task in English and Arabic among

English-Arabic school-aged children, such that performance was better in English than in Arabic. The direction of this effect may be linked to children's particular reading experience, but regardless of the direction and source of this difference, the findings demonstrate differential phonological awareness abilities in the two languages of bilingual children. Relatedly, Russak and Saiegh-Haddad (2011) documented better phoneme deletion and isolation in Hebrew than in English among adult Hebrew-English (HE) bilinguals.

Of relevance, performance of the same individuals in a given task that varies by the language of the stimuli suggests that phonological awareness performance cannot be explained by a single entity. One potential factor to contribute to this divergence is the phonological structure of the languages in question. Thus, the *Language Structure* view assumes that the phonotactic rules and phoneme accessibility of the specific language in question determine performance (Russak & Saiegh-Haddad, 2011; Saiegh-Haddad, 2007b). For example, because in Hebrew typical syllable structure holds a strong cohesion of the consonant–vowel (CV) unit (a body-coda CV-C structure, Russak & Saiegh-Haddad, 2017; Saiegh-Haddad, 2007a; Share & Blum, 2005), consonant clusters are rare, and as a consequence certain phonological awareness tasks such as initial phoneme segmentation or deletion are more difficult to perform (Ben-Dror et al., 1995; Russak & Saiegh-Haddad, 2017). At the same time, in English there is a strong cohesion of the VC rime unit (an onset-rime C-VC structure, *the Rime-Cohesion Hypothesis*, for example, De Cara & Goswami, 2002; Treiman, 1985). Consistent with this difference between Hebrew and English, whereas native English speakers find it easier to isolate onset phonemes (as the rime is more cohesive), native Hebrew speakers find it easier to isolate final phonemes (as do native Arabic speakers; for a review, see Saiegh-Haddad, 2019). Thus, the difference in performance between speakers of each language is presumably due to cross-linguistic differences in the underlying structure of the syllable and its distributional properties in the language (see also Russak & Saiegh-Haddad, 2017; Saiegh-Haddad, 2019).

Of relevance, the psycholinguistic realization of the language structure in question further depends on the accessibility of the linguistic representations in the speakers' mind. As emphasized by the *Phonological Representation Hypothesis* (Goswami, 2000) and the *Distinctness Hypothesis* (Elbro, 1996), the strength of linguistic representations at the phonological and lexical level affects phonological awareness abilities. According to the *Lexical Restructuring Model* (Walley et al., 2003), this ability naturally develops and improves along with vocabulary growth, word familiarity, and the increase of segmental representation. As a result, common words should be associated with stronger linguistic representations compared to unfamiliar words (see Russak & Saiegh-Haddad, 2011). Extending this line of thought to the bilingual case, because L1 words are assumed to be of higher frequency and familiarity for bilingual speakers compared to L2 words (Gollan et al., 2011; see also Kroll & Gollan, 2014), performance in phonological awareness tasks should be better on L1 versus L2 or pseudo words (Russak & Saiegh-Haddad, 2011). As a result, under the multiple-entity view, phonological awareness is expected to be dynamically modulated by speakers' proficiency.

Thus, according to the multiple-entity view, the availability of phonological representations within the individuals' mind, as determined by both the structures of the two languages of the speaker, and his or her exposure to and proficiency in the language in question affect phonological awareness abilities. Consistent with this conceptualization, in a recent review of the literature, Saiegh-Haddad (2019) proposed that phonological awareness in the L2 should be viewed as a dual-component ability, including a metalinguistic language-independent component and a language-specific linguistic component. Of relevance, this latter component is influenced by two sources of variability, namely, the *linguistic distance* between the two languages and *proficiency in the L2*. Whereas ample evidence has accumulated regarding the role of linguistic distance, as this dimension has been shown to constrain the degree of cross-language transfer and the sensitivity of different phonological awareness tasks to performance in each language (for a review, see Saiegh-Haddad, 2019), here we focus on the less studied source of L2 proficiency, as explained below.

Linguistic structure of Hebrew and English

The current study focuses on phonological awareness in Hebrew and English. The two languages in question differ in important ways in their phonological and morphological structure. As alluded to earlier, whereas in English the VC rime unit is cohesive (e.g., De Cara & Goswami, 2002; Treiman & Kessler, 1995), in Hebrew (Saiegh-Haddad, 2007a; as well as in Arabic, Saiegh-Haddad, 2007b, and Russian, Saiegh-Haddad et al., 2010), the core CV unit of the body appears to be the cohesive unit. This is in part because the CV unit is the most frequent phonological unit in Hebrew (Ben-David & Bat-El, 2016; Cohen-Gross, 2015; for a discussion, see Russak & Saiegh-Haddad, 2017; Saiegh-Haddad, 2019). As a result, performance on phonological awareness tasks that differentially tap these two sub-syllabic structures is expected to differ by language. For instance, the rhyme judgment task (as utilized in the current study) is especially sensitive to the VC rime unit as it requires speakers to determine whether word final phonological units overlap across two instances. Thus, performance should be easier on English than on Hebrew words in this task. At the same time, morphological differences between Hebrew and English may lead to a different pattern. Specifically, the VC rime unit may coincide in Hebrew with the word template morphological unit (vocalic pattern), which are frequent units in the language. Thus, rhyme judgments on Hebrew words in which a morphological unit appears as the VC unit may be easier than rhyme judgments on English words.

L2 proficiency

The considerations described above predict phonological awareness performance that is linked to the structural properties of the language in question. Thus, performance may be better in English than in Hebrew due to the rime cohesiveness in English or may be better in Hebrew than in English due to the morphological structure. Critically, if these differences alone determine performance on the phonological awareness task, then all participants, regardless of their proficiency profile, should exhibit the same pattern. However, if the psycholinguistic realization of these language properties affects performance, then participants' proficiency in the language and the availability of the representations in each language should modulate performance. Thus, in the current study, we go beyond these important language properties to test whether performance is influenced by individuals' proficiency in the languages in question.

To this end, we test two groups of bilingual speakers who differ in their language proficiency profile. Specifically, HE bilinguals with Hebrew as their native language and English as their L2 are compared to English-Hebrew (EH) bilinguals, who are native English speakers and learned Hebrew as an L2. To the extent that language proficiency modulates the availability of phonological representations, then the two groups are expected to differ in their performance pattern across languages with better performance on the more dominant language in which representations are more available. Specifically, HE bilinguals are expected to perform the rhyme judgment task better in Hebrew, their dominant language, than in English, whereas the EH bilinguals are expected to perform better in English, their dominant language, than in Hebrew. By utilizing the same stimuli set for both groups, the current study sheds light on the relative role of language proficiency, above and beyond language-specific structural differences.

Characteristics of the task

The reviewed literature suggests that there is reason to expect phonological awareness performance to vary as a function of the characteristics of the languages as well as participants' proficiency profile. In addition, task characteristics may also affect the observed pattern. Indeed, different phonological awareness tasks have been used in the literature (Branum-Martin et al., 2015; Russak & Saiegh-Haddad, 2011), giving rise to differential developmental results (e.g., Saiegh-Haddad, 2007a). Here, we opted to use a rhyme judgment task (e.g., Nation & Snowling, 2004; Wagensveld et al., 2013). This task has been used in previous research with children (e.g., Nation & Snowling, 1998, 2004), and sensitivity to the presence of a rhyme was more generally assessed in other paradigms (e.g., rhyme oddity and rhyme detection tasks; for a review, see Branum-Martin et al., 2012, 2015). These rhyme-based decision tasks are thought to tap epilinguistic, implicit phonological processing (Gombert, 1992), in contrast to "deeper" phonological awareness tasks that are more dependent on explicit reflective and intentional processes (such as phoneme isolation; see Saeigh-Haddad, 2007a). Because our focus was on the role of language proficiency and the way it modulates processing of phonological representations, an implicit, processing-based task, like the rhyme judgment task, was suitable. Furthermore, because such epilinguistic tasks are thought to be relatively easy (Adams, 1990; Saiegh-Haddad 2007a), we opted to use a timed variant of the rhyme judgment task to allow sensitivity to performance of adult speakers, avoiding a ceiling effect.

The current study

To test the prediction of the multiple-entity view, by which linguistic structure and L2 proficiency modulate phonological awareness performance, in the current study we utilized a rhyme judgment task including English, Hebrew, and Pseudo-Hebrew word-pairs and tested two groups of participants who vary in their language proficiency profile. HE bilinguals with Hebrew as their native language and English as their L2 (tested in Experiment 1a) were compared to EH bilinguals, who were native English speakers and learned Hebrew as an L2 (*tested in* Experiment 1b). If phonological awareness is a single entity, then similar performance is expected across the three conditions of the task (English, Hebrew, Pseudo-Hebrew) within each bilingual group and should correlate across languages. If, however, a multiple-entity view is accepted, then bilinguals' rhyme judgment performance may differ across the languages of the task. Critically, because the targeted languages Hebrew and English differ in their phonological and morphological structure, performance on the two languages may differ by virtue of the properties of the language, with better performance in English than in Hebrew (due to the rime cohesiveness in English) or with better performance in Hebrew than in English (due to the role of Hebrew morpho-phonological word pattern template).

Of relevance, the linguistic distance component by which differences in phonological structure across languages affect phonological awareness performance would lead to differences between Hebrew and English that are stable across the two bilingual groups. Thus, to the extent that the structural properties of the languages in question (Hebrew vs English) allow for better rhyme judgment performance, then both bilingual groups should pattern in the same way, with better performance in English than in Hebrew, or in Hebrew than in English. Furthermore, if L2 proficiency additionally modulates phonological awareness performance, then performance should pattern with language dominance. Accordingly, the prediction would be that HE bilinguals would perform better on Hebrew (L1) pairs compared to English (L2) pairs, whereas EH bilinguals would perform better on English (L1) pairs compared to Hebrew (L2) pairs.

Performance on the Pseudo-Hebrew words may resemble that of the Hebrew words, if performance is most prominently determined by the *morpho-phonological* distributional properties of the language in question. However, if the strength of *lexical* representations further modifies phonological awareness performance, then pseudo-Hebrew words should result in lower performance compared to the Hebrew words (Russak & Saiegh-Haddad, 2011). Thus, the findings of the current study may provide insight into the components contributing to phonological awareness abilities in bilinguals' languages.

Method

Experiment 1a—HE bilinguals

Participants. Thirty HE bilinguals (9 males; mean age = 27.9, *SD* = 1.95) participated in this experiment. They were native Hebrew speakers who grew up and were residing in a Hebrew speaking environment, and learned English as an L2 in school. Participants were recruited through social networks, volunteered to participate, and signed an informed consent prior to participation. All participants had Hebrew as their dominant language, as determined by self-report using a detailed language history questionnaire (adapted from the Language Experience and Proficiency Questionnaire [LEAP-Q], Marian et al., 2007). Moreover, objective proficiency measures tapping lexical retrieval abilities in Hebrew and English (semantic fluency tasks in each language) were administered to confirm this dominance pattern. One participant did not complete the language history questionnaire and was therefore excluded from analysis. Background characteristics of the final set of 29 participants are presented in Table 1 in comparison with those of the EH bilinguals tested in Experiment 1b.

Materials and procedure. Each participant was tested individually in a quiet room on a laptop computer with headphones and designated response box (E-prime Chronos; Psychology Software Tools, Pittsburgh, PA). All communication was carried out naturally in Hebrew with an HE bilingual experimenter. Following a consent form, participants completed the rhyme judgment task followed by the semantic fluency tasks in Hebrew and English, and the language history questionnaire. The entire protocol lasted about 1 hour.

Rhyme judgment task. Stimuli included 270 word-pairs in one of three language conditions: English, Hebrew, and pseudo-Hebrew (90 pairs in each, see stimuli list in Appendix 1). All stimuli were recorded by the same female bilingual speaker of English and Hebrew, who recorded English words in an English-like pronunciation, and Hebrew and pseudo-Hebrew words in a Hebrew-like pronunciation. Because bilinguals respond differently to words that share phonological structure and meaning across languages (i.e., cognates, e.g., Hoshino & Kroll, 2008), stimuli in the English and Hebrew lists did not include cognates, and concepts were not repeated across languages. Furthermore, stimuli with ambiguous phonology-to-spelling correspondence were avoided. Pseudo-Hebrew pairs used the Hebrew phonemic repertoire, did not violate Hebrew phonotactic rules, but were not constructed from specific Hebrew roots, templates, or items. Importantly, they were not associated with meaning in either Hebrew or English.

Critically, across the three language conditions, half of the pairs included overlapping phonological units in the final syllable requiring a "yes" rhyme decision (see Table 2), whereas the other half did not include overlapping final syllables, requiring a "no" rhyme decision. Across the three language conditions, roughly half of the "yes" pairs shared the exact same phonological structure (e.g., if the first word is a ccvc, so was the second one). Of the items requiring a "yes" decision,

Table 1. Participant's characteristics as a function of language background group.

Measure	Language background	
	Experiment 1a Hebrew-English bilinguals	Experiment 1b English-Hebrew bilinguals
Number of participants	29	33
Gender	(9 males)	(14 males)
Age (in years)*	27.90 (1.95)	32.27 (8.09)
Education (in years)*	15.86 (1.47)	17.59 (3.00)
SES—maternal education (in years)	16.17 (3.74)	17.97 (4.38)
English overall proficiency*	7.04 (1.04)	9.88 (0.32)
English oral proficiency*	7.34 (1.11)	9.92 (0.22)
English use*	5.87 (1.62)	7.48 (1.27)
Age began learning L2 (in years)*	8.10 (1.78)	9.79 (8.37)
Hebrew overall proficiency*	9.44 (0.53)	6.69 (1.38)
Hebrew oral proficiency*	9.41 (0.63)	7.58 (1.42)
Hebrew use*	7.38 (0.97)	4.61 (1.49)
Language mixing habits	4.48 (3.04)	5.48 (3.01)
English semantic fluency ("vehicles")*	10.21 (2.47)	12.45 (5.08)
Hebrew semantic fluency ("animals")*	24.21 (5.33)	13.68 (6.54)

Note: SDs appear in parentheses. Self-rated proficiency is on a scale of 0–10, with 0 indicating the *lowest level of ability* and 10 indicating the *highest level of ability*. Oral proficiency is computed as the average self-report score of talking and comprehending. L1 and L2 use is the averaged rated use in speaking, writing, reading, listening to radio, and watching TV on a scale of 0–10, with 0 indicating the *lowest level of use* and 10 indicating the *highest level of use*. Language switching habits is on a scale of 0–10, with 0 indicating *lowest levels of switching* to a different language in a conversation with a proficient bilingual and 10 indicating the *highest levels*.
*A significant difference between the language background groups at the $p < .05$ level.

Table 2. Stimulus characteristics.

Measure	Word type		
	English pairs	Hebrew pairs	Pseudo-Hebrew pairs
Number of pairs	90	90	90
Averaged item frequency*	107.30 (268.90)	30.70 (66.10)	N/A
Part of speech (% nouns)	88.90	89.50	N/A
Averaged number of syllables*	1.48 (0.60)	2.21 (0.41)	1.96 (0.67)
Monosyllabic words (%)	63	3	25
Bi-syllabic words (%)	27	74	57
Multiple syllable words (%)	9	23	18
Shared syllabic structure	23	23	24
Basis for "Yes" rhyme decision			
Part of syllable	31	14	0
Whole syllable	4	35	6
More than a syllable	15	28	2

Note: SDs appear in parentheses. There were significant differences across word types (at the level of $p < .05$, marked by *) in number of syllables and item frequency. Note, however, that Hebrew frequency is based on HebWaC corpus via Sketch-Engine (see Kilgarriff et al., 2014), whereas English frequency is based on the SUBTLEXUS frequency from Brysbaert and New (2009). Because frequencies in each language are based on separate and different corpora, the significant difference between the two-word types should be taken with caution.

more words in Hebrew shared the entire syllable compared to English (see Table 2 and Appendix 1). This is in line with the difference across the two languages in syllable length, which was statistically controlled for in the analysis. Of note, if greater phonological overlap facilitates rhyme decision, all participants, regardless of proficiency profile, should exhibit this tendency. English and Hebrew items also differed in item frequency, which was similarly controlled for in the analyses. Finally, 17 Hebrew word-pairs in the "yes" condition adhered to a morphological word-pattern that could facilitate rhyme decisions because the final syllable was part of this word-pattern (see Appendix 1). However, because these properties were not targeted in the current design, and were not manipulated as such, there were not enough items to examine this issue systematically (but see Russak & Saiegh-Haddad, 2011).

Of the "no" rhyme pairs in English and Hebrew, stimuli were further sub-divided into three pair types: (1) semantically related pairs (e.g., "purse–bag"); (2) translated rhyme pairs (e.g., "monkey–drum" translated into Hebrew as a rhyme /kof/-/tof/); and (3) non-related pairs (e.g., "oven–letter"). These sub-types were included to allow examination of how strength of lexical representations and cross-language activation modulate rhyme judgment performance. Notably, however, preliminary analysis revealed no influence of this sub-division, and these were therefore collapsed in current analyses.

In the rhyme judgment task, participants were instructed in their dominant language to decide whether each word-pair presented auditorily rhymed or not, by pressing the response box as quickly and as accurately as possible. No definition of what constitutes a rhyme was given, such that participants were free to base their decision on their intuitive understanding of the concept, following the four practice items given. We return to this issue in the discussion. Each trial began with a fixation cross at the center of the computer screen, followed by a 1,000-ms silent pause. The first word of the pair was then auditorily presented, followed by a silent pause of 1,000 ms. The second word was then auditorily presented, followed by another silent 1,000 ms interval. A question mark then appeared on the screen, and participants were to press "√" to indicate a "yes" response or an "X" to indicate a "no" response, with their dominant hand. Participants' reaction times (RTs) (in ms, from the onset of the question mark) and accuracy were recorded by the computer program. No feedback was given throughout the task. Presentation order was randomized by the computer program, and experimental trials were interleaved with an optional short break. Four practice trials preceded the experimental trials.

Semantic fluency task. Participants performed a semantic fluency task on one category in each language, "Animals" in Hebrew and "Vehicles" in English (Kavé, 2005). For each category, participants were asked to produce as many words as possible within 1 minute, signaled by an animated hourglass on the screen. Responses were recorded for later coding. As these categories differ in their density (Animals being a wider category than Vehicles), fluency scores served for between individual comparisons, as well as to verify participants dominance profile (Hebrew vs English) in the two groups tested in Experiments 1a and 1b.

Language history questionnaire. Participants' language background information was collected using a detailed language-history questionnaire fulfilled with the experimenter (modified from LEAP-Q, Marian et al., 2007).

Experiment 1b—EH bilinguals

In addition to providing a comparison to the HE bilinguals tested in Experiment 1a, the original goal of Experiment 1b was also to examine whether short-term changes in language context affect performance in the rhyme judgment task. Our original reasoning here was that language context may affect the accessibility of linguistic representations (Degani et al., 2020; Kreiner & Degani, 2015), such that it may dynamically affect participants' ability to perform the rhyme judgment task in each language. Thus, participants performed half of the trials (i.e., 135 word-pairs, including English, Hebrew, and pseudo-Hebrew pairs) before a brief exposure manipulation, including either watching an English movie or playing a non-linguistic computer game for 10 minutes, and one-half following this exposure. However, because stimuli lists were unintentionally not properly counterbalanced before and after exposure, and because there were no reliable brief exposure effects, these analyses are reported in Appendix 6 and are not discussed further. For the purpose of the current study, performance in the pre-exposure phase only is considered, consisting of 135 trials. These pre-exposure trials are compared to the first 135 trials completed by the HE bilinguals tested in Experiment 1a.

Participants. A total of 60 EH-speaking participants (26 males; mean age = 34.7, *SD* = 10.9), who grew up in an English-speaking country and studied Hebrew as an L2, took part in the experiment. At the time of testing, participants were residing in Israel, in which the environmental language is Hebrew. Participants were recruited through social media networks and were paid for their participation. They had English as their dominant language, as determined by self-report using the detailed language history questionnaire (adapted from the LEAP-Q, Marian et al., 2007), and verified using the objective proficiency measure (semantic fluency in each task).

Of these participants, nine were excluded because: they were born in a non-English-speaking country (two participants); were exposed to Hebrew from birth (four participants); or due to technical difficulty in task administration (three participants). In addition, of the remaining 51 participants, there were 8 who reported having a learning disability or attention deficits, 3 who were more than 3 *SD* above study mean age, 2 who reported low Hebrew proficiency (subjectively rating their Hebrew proficiency below 3 on a 0–10 scale), and 5 who experienced distractions during task administration, including background linguistic exposure. Analyses were conducted with and without these participants and yielded the same patterns. Thus, analysis based on the smaller group ($n = 33$) is presented here (see Table 1 for background characteristics).

Materials and procedure. Experimental materials and procedure were identical to those used in Experiment 1a, with two exceptions. First, in Experiment 1b, the rhyme judgment task was divided into two blocks (each containing 135 pairs, with 45 pairs in each language condition, matched on syllable length, item frequency, and part-of-speech—see Appendix 2), interleaved with a 10-minute exposure task (watching an English movie or completing a non-linguistic computerized game). As explained above, only the first of these blocks, which was identical for all participants, is analyzed here. Second, the semantic fluency task included two categories in each language ("Animals" and "Professions" in Hebrew, followed by "Fruits and Vegetables" and "Vehicles" in English). Comparisons across the two bilingual groups focus on the shared categories (Animals and Vehicles, see Table 1).

Results

Data analysis approach

To examine performance in the rhyme judgment task, *d′* were computed for each participant to reveal participants' sensitivity in each pair type (English, Hebrew, pseudo-Hebrew). This measure subtracts the normalized false-alarm rate from the normalized hit rate, thus controlling for

Table 3. Reaction times on correct responses (top) and percentage of errors (bottom) in the rhyme judgment task, as a function of response, group, and type of item.

	Response type			
	Yes responses		No responses	
Reaction times (ms)	HE bilinguals	EH bilinguals	HE bilinguals	EH bilinguals
English pairs	273 (118)	303 (149)	283 (136)	292 (142)
Hebrew pairs	277 (125)	325 (151)	277 (127)	307 (142)
Pseudo-Hebrew pairs	320 (146)	359 (164)	292 (134)	313 (143)
% Errors				
English pairs	0.09 (0.30)	0.12 (0.35)	0.01 (0.13)	0.00 (0.07)
Hebrew pairs	0.02 (0.17)	0.09 (0.29)	0.01 (0.12)	0.05 (0.25)
Pseudo-Hebrew pairs	0.13 (0.37)	0.18 (0.40)	0.01 (0.09)	0.01 (0.14)

HE: Hebrew-English; EH: English-Hebrew.
*SD*s appear in parentheses.

participants' response bias. To examine the within-participant interdependence of sensitivity in the two languages of bilingual speakers, the correlation between the *d′* for Hebrew pairs and the *d′* for English pairs within each bilingual group were examined. In addition, RTs were analyzed using linear mixed-effects models, as these models allow one to simultaneously account for variance related to participants and to items. For completeness, error rate data are presented in Table 3 and their analyses reported in Appendix 5. RTs on correct responses were trimmed to remove trials on which latencies were more than 2.5 *SD* from the mean of each participant on correct responses (excluding about 8% of the data). To verify excluded data did not change results, analyses were conducted with and without these exclusions and yielded the same pattern of results (see Appendix 3 for raw data analysis). Models were fit using the *buildmer* function in the *buildmer* package (v. 1.3, Voeten, 2019) in R (version 3.6.1, R Core Team, 2019), which uses the *lmer* function from the *lme4* package (v 1.1.-21, Bates, Maechler, et al., 2015). Using backward stepwise elimination, the *buildmer* function starts from the most complex model and systematically simplifies the random structure until the model converges. Once the maximally converging model as supported by the data has been identified (Bates, Kliegl, et al., 2015), the function calculates *p*-values for all fixed effects based on Satterthwaite degrees of freedom using the *lmerTest* package (v. 3.1-0, Kuznetsova et al., 2017). When necessary, to probe interactions and examine pairwise comparisons, the selected model was refitted using *lmer* and followed by the *testInteractions* function from the *phia* package (v. 0.2-1, De & Rosario-Martinez, 2015) with Bonferroni adjustments for multiple comparisons.

The models included the first 135 trials of the HE bilinguals and the pre-exposure block of the EH bilinguals (see Table 3 for descriptive statistics of performance). The maximal models submitted to the *buildmer* function included Group (HE vs EH, with EH set as the reference), Type (English, Hebrew, and pseudo-Hebrew with English set as the reference), and Rhyme Response (Yes vs No, with No set as the reference) and the interactions among them. Random effects included by-participant and by-item intercepts, as well as by-participant slopes for Response and Type and their interaction, and by-item slope for Group.

To account for baseline differences among the pair types in syllable length, this factor was normalized and included as a control variable. To control for frequency differences between the English and Hebrew items, and because the corpora over which these frequencies were calculated

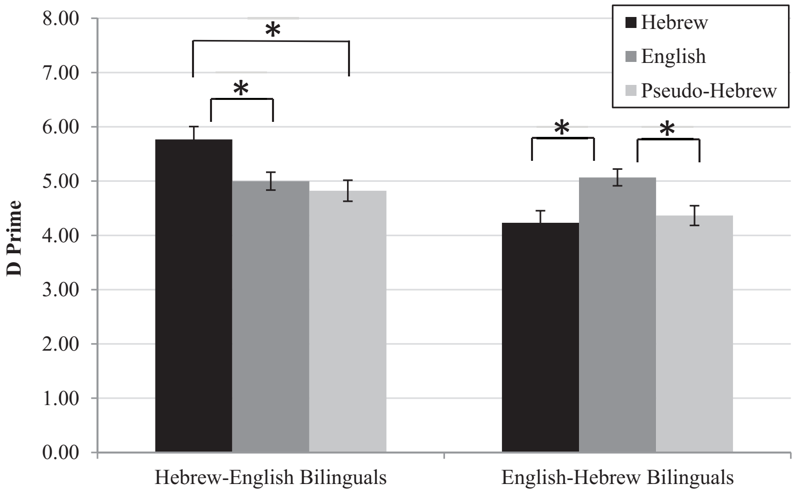

Figure 1. Estimated *d′* in the rhyme judgment task as a function of group and pair type (error bars represent *SE*).

differ, the frequency counts were normalized within each language and this normalized score was used as a control variable. Pseudo-Hebrew words were assigned a value of −1 for these calculations (the minimum normalized score in this sample for Hebrew and English was −0.5). Furthermore, to control for baseline differences between EH and HE bilinguals, age, education, and socioeconomic status (SES) were normalized and included as control variables. Below we report significant findings and present the selected models from the Anova function. Full summary of the models and of the pairwise comparisons with Bonferroni corrections are presented in Appendix 4.

Sensitivity—*d′*

Comparing HE with EH bilinguals. Because the rhyme judgment task entails a yes/no decision component, participants may exhibit a bias in their responses. To account for this, we computed *d′* for each participant in each type. Repeated-measures ANOVA with Type as a within-participant factor and Group as a between-participant factor on *d′* revealed a main effect of type ($F(2,120)=2.81$, $MSE=0.97$, $p=.025$, $\eta_p^2=.06$), a main effect of group ($F(2,60)=12.17$, $MSE=1.57$, $p=.001$, $\eta_p^2=.17$), and a significant interaction ($F(2,120)=10.63$, $MSE=0.97$, $p<.001$, $\eta_p^2=.15$; see Figure 1). Follow-up tests within each group, followed by pairwise comparisons with Bonferroni corrections, revealed a significant effect of Type for EH bilinguals ($F(2,64)=5.91$, $MSE=1.13$, $p=.004$, $\eta_p^2=.16$), such that their sensitivity was significantly higher for English pairs compared to the other two types, which did not differ from each other. For HE bilinguals, the Type effect was significant as well ($F(2,56)=9.24$, $MSE=0.79$, $p<.001$, $\eta_p^2=.256$), with sensitivity being higher for Hebrew pairs compared to the other two types, which did not differ from each other.

Correlations between performance in Hebrew versus English. To uncover the degree to which the individual's performance in each language was independent of his or her performance in the other language, we examined the correlation between the *d′* of Hebrew and the *d′* of English pairs within and across the bilingual groups. These analyses revealed that across the entire sample ($r(62)=.12$, $p=.34$), as well as in the HE ($r(29)=.18$, $p=.34$) and EH ($r(33)=.17$, $p=.34$) bilinguals separately, there was no correlation between the sensitivity to rhymes in English and in Hebrew (see Figure 2).

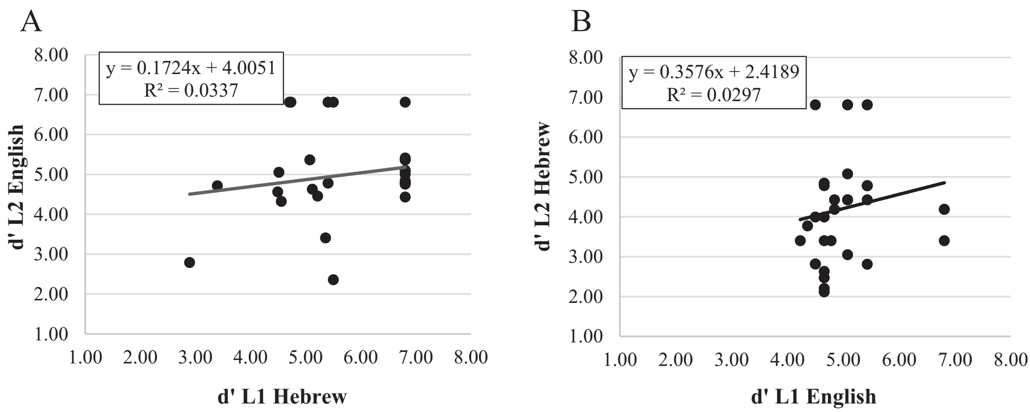

Figure 2. Correlation between *d*' on L1 and L2 pairs in the (A) Hebrew-English bilingual group and the (B) English-Hebrew bilingual group.

Table 4. Selected model summary predicting RT on correct responses.

RTs (ms) on correct responses					
Fixed effects	*MSS*	Num. *df*	Den. *df*	*F*-value	*p*-value
(Normalized) Age	145,499	1	62	8.86	.004**
Type	829,607	2	6,794	50.49	<.001***
(Normalized) Syllable length	115,673	1	62	7.04	.01*
Group	84,802	1	62	5.16	.03*
Response	490,095	1	6,798	29.83	<.001***
Type × Response	227,345	2	6,794	13.84	<.001***
Group × Response	98,268	1	6,797	5.98	.01*
Type × Group	64,736	2	6,794	3.94	.02*

RT: reaction time. MSS: Mean Sum of Squares.
* $p < .05$; ** $p < .01$; *** $p < 0.001$.

Reaction times

Table 3 presents mean performance as a function of Response (yes vs no), Group (EH vs HE) and Type (English, Hebrew, pseudo-Hebrew). The RT analyses revealed that RTs increased with age but decreased with average syllable length. Of relevance, there were main effects for Response, Type, and Group that were qualified by two-way interactions between Response and Type, Response and Group, and critically Type and Group (see Table 4 and corresponding Appendix 4).

Follow-up tests with Bonferroni corrections for multiple comparisons revealed that RTs were slower for Yes than for No responses only for pseudo-Hebrew words, and that this Response effect was significant for EH bilinguals but only marginal for HE bilinguals. Most critically, collapsing across response type, for EH bilinguals, responses were significantly faster for English pairs than for Hebrew pairs which in turn were significantly faster than the pseudo-Hebrew pairs. For HE bilinguals, responses were equally fast for Hebrew and English pairs, which were both faster than responses to pseudo-Hebrew pairs (see Figure 3 and Appendix 4 for all pairwise comparisons).

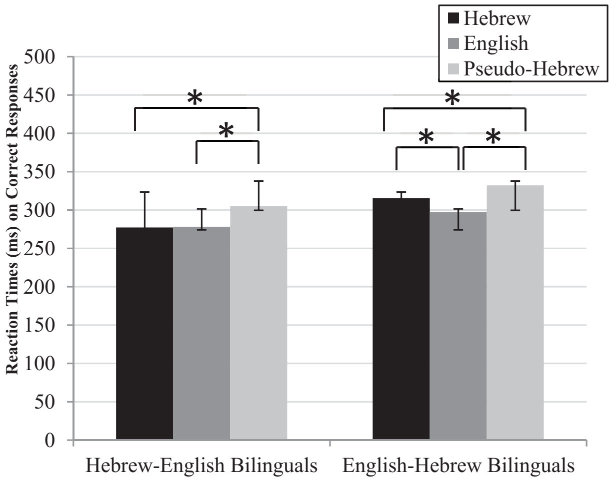

Figure 3. Estimated reaction times on correct responses in the rhyme judgment task as a function of group and pair type (error bars represent *SE* calculated for within-participant variables following Morey, 2008).

Discussion

The goal of the present study was to examine whether bilinguals' phonological awareness reflects a single entity, or whether it reflects multiple entities such that phonological awareness performance varies between the L1 and L2 of bilingual speakers. Comparing two groups of bilinguals who differ in their proficiency profile, we observed that rhyme judgment performance on the same set of words was affected by participants' proficiency profile. In particular, HE bilinguals exhibited increased sensitivity to Hebrew (L1) pairs compared to English and pseudo-Hebrew pairs, as reflected in a d' measure, whereas EH bilinguals exhibited increased sensitivity to their L1 (English) compared to Hebrew and pseudo-Hebrew pairs. Furthermore, EH bilinguals responded significantly more quickly to English pairs, compared to Hebrew pairs, which in turn were faster than pseudo-Hebrew pairs. The advantage in RT for English pairs was not observed in the HE bilingual group, who responded equally fast to Hebrew and English pairs, which in turn were both faster than pseudo-Hebrew pairs.

Phonological awareness as a multiple entity

Most prominently, these findings demonstrate that phonological awareness performance varies between the two languages of bilingual speakers. In both bilingual groups, we observed differential performance in Hebrew and English, suggesting that phonological awareness in one language is not fully determined by this ability in the other language. The current findings are in line with previous results showing differences in bilinguals' phonological awareness performance in their two languages (Russak & Saiegh-Haddad, 2011, with adult HE bilinguals) and the suggestion that phonological awareness is part of one's language representations (e.g., the Linguistic Affiliation Hypothesis, Russak & Saiegh-Haddad, 2011, 2017; Saiegh-Haddad, 2007b; Swan & Goswami, 1997; White et al., 2017).

Interestingly, the current study sheds light on the particular components that operate to affect phonological awareness. Specifically, the structural differences between the languages in question would have predicted that all participants would respond better to stimuli in a given language compared to the other language. The same ordered performance was predicted regardless of proficiency profile. If the phonological structure of the language is most critical, then the cohesiveness of the VC rime unit in English should have led to better performance on English than on Hebrew pairs. In contrast, if the morpho-phonological structure of Hebrew and the presence of the word pattern template are crucial, then performance on these Hebrew word-pairs was expected to be better than on English word-pairs for all participants (though because the presence of word pattern templates was not systematically manipulated, more work may be revealing here).

Going beyond these predictions, however, the current results revealed modulations by proficiency profile, in that the EH bilinguals processed English pairs better, whereas the HE bilinguals processed Hebrew pairs better. The results are therefore consistent with the suggestion that the strength of the linguistic representations in the speakers' mind affect his or her ability to perform a phonological awareness task (Walley et al., 2003). Bilinguals across both groups determined the rhyme status of pairs in their L1 better than pairs in their L2. Presumably, long-term accumulated language use increased the frequency and availability of linguistic representations in the more dominant language. This in turn modulated the ease with which different bilingual groups performed the rhyme judgment task in each language.

The current findings underscore the relevance of the availability of linguistic representations as the basis for phonological awareness performance. Notably, these linguistic representations may entail both lexical and sub-lexical (phonological) representations, and these may both be at play. In the current study, the difference in processing of Hebrew versus English word-pairs could be due to differences in the strength of *lexical* representations, as words in the L1 and L2 are likely to differ in their respective frequency and thus availability (e.g., Gollan et al., 2011). At the same time, frequency of exposure to each language may also affect the availability of and familiarity with *sub-lexical* (phonological) representations of each language, such that the strength of phonological representations may similarly affect bilinguals' performance in their L1 and L2. The advantage for phonological awareness performance in the dominant language observed here cannot dissociate these two sources. However, one aspect of our study supports the unique contribution of lexical knowledge. Specifically, processing of Hebrew words was superior to that of pseudo-Hebrew words, in both the d' and RT measures for the HE bilinguals. The same numeric pattern was observed for EH bilinguals as well. As the critical difference between Hebrew and pseudo-Hebrew items is the lexical status of their referents, the difference between them provides suggestive evidence that the strength of lexical representations contributes to sub-lexical, phonological, awareness. This suggestion is consistent with the *Lexical Restructuring Model* (Walley et al., 2003) and previous studies in which language membership and lexical status were directly manipulated (e.g., Russak & Saiegh-Haddad, 2011).

Moreover, in addition to speakers' exposure to each language, which affects the accessibility of linguistic representations, cross-language overlap may further affect their availability. For instance, a rhyme judgment decision may be easier on pairs that include shared phonemes across languages, than on pairs that include language-specific phonological units (e.g., a vowel contrast that exists in one language but not the other). Structural differences across languages may constrain the degree to which lexical and sub-lexical units are shared across languages. Systematically quantifying the contribution of language exposure and cross-language influences to bilinguals' phonological awareness performance is, however, beyond the scope of this study (but see Kuo & Anderson, 2010).

Of relevance, the association between participants' proficiency and their phonological awareness performance in a given language may reflect reciprocal relations, such that proficiency improves phonological awareness, and phonological awareness improves proficiency. Such bidirectional links have been central to the relation between phonological awareness and literacy development (Castles & Coltheart, 2004), and evidence indeed suggests that not only phonological awareness affects reading development (e.g., Tornéus, 1984) but also knowledge of orthographic representations and learning to read affect the way speakers perceive and operate over phonological representations (e.g., Ben-Dror et al., 1995; Goswami et al., 2005). Accordingly, the observed relation between language proficiency and phonological awareness may reflect not only the fact that speakers are better able to manipulate the sound components when the strength of linguistic representations are higher, but also that increased phonological awareness abilities promote speakers' ability to acquire spoken and written proficiency in the language (see related discussion regarding reading disabled individuals in Russak & Saiegh-Haddad, 2011). Future longitudinal or intervention studies may reveal the nature of this causal relation.

Independence across the two languages

In the current study, participant's rhyme judgment sensitivity in one language was not correlated with his or her sensitivity in the other language. This independence of phonological awareness in the two languages was observed for both the HE and the EH bilinguals. The finding is at odds with previous studies documenting correlations between bilingual children's phonological awareness in their two languages (Bialystok et al., 2005; Durgunoğlu et al., 1993; Geva & Siegel, 2000). This correlation was interpreted to suggest the reliance of phonological awareness in the L2 on phonological awareness abilities in the L1 (Navarra et al., 2005; Simon et al., 2014). Of note, most of these studies were conducted with children who are still developing and establishing the components of their phonological awareness abilities, whereas the current study examined typical adult population. It is possible that the reliance on L1 representations in L2 phonological awareness tasks is diminished for more proficient speakers, as may be the case for adult speakers. Furthermore, the structural difference between L1 and L2 may similarly constrain the degree to which phonological awareness in the L1 can serve as the basis for phonological awareness in the L2 (Saiegh-Haddad, 2019). Future studies which directly compare children and adults on the same tasks (Baker et al., 2008; Simon et al., 2014), and that compare more and less similar languages (Bialystok et al., 2005), will be informative in this respect.

Furthermore, in the studies that observed correlations across languages, phonological awareness was examined with other tasks that may rely to a different extent on the strength of linguistic representations. For instance, Durgunoğlu et al. (1993) tested phonological awareness with segmenting and blending assignments, whereas Bialystok et al. (2005) evaluated phonological awareness by phoneme counting and nonword decoding. Different tasks vary in the extent to which they highlight cross-linguistic differences in phonological awareness (Branum-Martin et al., 2015) and may similarly vary in the degree to which they rely on the strength of linguistic representations and depend on language proficiency. Specifically, the rhyme judgment task utilized here may be considered an epilinguistic task (Gombert, 1992), which relative to "deeper," more explicit metalinguistic awareness tasks relies more on implicit phonological processing skills. As such, the rhyme judgment task is likely to be influenced by language-specific experience more than other, more meta-cognitive tasks such as phoneme segmentation or deletion (Saiegh-Haddad, 2007a). These considerations raise the possibility that the observed language-dependent effects may be exaggerated by the nature of the task used here. Future work in which deeper phonological awareness tasks are utilized are important in this respect. Relatedly, as the task is designed to test implicit phonological processing, instructions were kept to a minimum, and participants were to base their judgments on their intuitive understanding of the task. This aspect likely increased variability in our sample. Critically, however, given that a within-participant design was used, participants' interpretation of the task likely guided their decisions across all item types. Furthermore, such rhyme judgment tasks are commonly used in educational and clinical practices, and thus understanding the degree to which performance on this task in one language predicts performance in another is of great practical relevance, as described below.

Implications for the theory of phonological awareness and clinical practice

The current study suggests that phonological awareness of bilingual speakers cannot be explained by a single entity approach and is influenced by the strength of linguistic representations. This is evident in three aspects of the findings. First, all bilingual participants exhibited enhanced phonological awareness sensitivity to items in their more dominant compared to their less dominant language. Second, there was no correlation between participants' performance in the two languages. Third, strength of item representations, as reflected by item frequency, predicted performance, such that rhyme judgments on more strongly represented items (i.e., more frequent items) were better than rhyme judgments on weaker represented items.

Thus, extending the extensive line of research documenting the influence of language structure and linguistic distance on phonological awareness performance (see Janssen et al., 2017; for a recent review, see Saiegh-Haddad, 2019), the current findings highlight the importance of language proficiency as a central component in a multiple-entity view of phonological awareness. Because responses to the same set of linguistic items (e.g., Hebrew pairs) were consistently modulated by participants' proficiency profile, the findings lend support to the important role of the strength of linguistic representations within the speakers' mind. Phonological awareness abilities are therefore better conceptualized as dependent, at least to some extent, on participants' language proficiency. At the same time, domain-general cognitive or auditory abilities may further contribute to participants' performance (see also Saiegh-Haddad, 2019).

Importantly, we did not observe any correlation between performance in the two languages of the same individuals. This suggests that reliance on speakers' rhyme judgment in one language as a proxy for his or her ability in the other language is unwarranted. This is a critical consideration for clinical and educational practice. The extent to which similar independence is observed beyond the typical adult population tested here awaits additional research.

Conclusion

The above findings underscore the complex nature of phonological awareness and the strong impact of language proficiency on this important ability. Two groups of bilingual adults exhibited better performance in a phonological awareness task in the language they were more proficient in (i.e., their L1) compared to their less proficient language (L2). The results support the suggestion that the strength of linguistic representations affect phonological awareness performance above and beyond the phonological structure of a specific language. Phonological awareness emerges as a multiple-entity complex ability, heavily influenced by speakers' strength of linguistic representations, as indexed by their language proficiency profile. Further research is needed to determine whether phonological awareness performance can be dynamically modulated by short-term modulations of language accessibility.

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References

Adams, M. J. (1990). *Beginning to read: Thinking and learning about print*. Cambridge MA: MIT Press.

Baker, W., Trofimovich, P., Flege, J. E., Mack, M., & Halter, R. (2008). Child–adult differences in second language phonological learning: The role of cross-language similarity. *Language and Speech*, *51*, 317–342. https://doi.org/10.1177/0023830908099068

Bates, D., Kliegl, R., Vasishth, S., & Baayen, H. (2015). *Parsimonious mixed models*. https://arxiv.org/abs/1506.04967

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, *67*, 1–48. https://doi.org/10.18637/jss.v067.i01

Ben-David, A., & Bat-El, O. (2016). Paths and stages in the acquisition of Hebrew phonological word. In R. A. Berman (Ed.), *Acquisition and development of Hebrew: From infancy to adolescence* (pp. 39–68). John Benjamins.

Ben-Dror, I., Bentin, S., & Frost, R. (1995). Semantic, phonologic, and morphologic skills in reading disabled and normal children: Evidence from perception and production of spoken Hebrew. *Reading Research Quarterly*, *30*, 876–893. https://doi.org/10.2307/748202

Bialystok, E., Luk, G., & Kwan, E. (2005). Bilingualism, biliteracy, and learning to read: Interactions among languages and writing systems. *Scientific Studies of Reading*, *9*(1), 43–61. https://doi.org/10.1207/s1532799xssr0901_4

Brady, S., & Shankweiler, D. (1991). *Phonological processes in literacy: A tribute to Isabelle Y. Liberman*. Lawrence Erlbaum.

Branum-Martin, L., Mehta, P. D., Fletcher, J. M., Carlson, C. D., Ortiz, A., Carlo, M., & Francis, D. J. (2006). Bilingual phonological awareness: Multilevel construct validation among Spanish-speaking kindergarteners in transitional bilingual education classrooms. *Journal of Educational Psychology*, *98*(1), 170–181. https://doi.org/10.1037/0022-0663.98.1.170

Branum-Martin, L., Tao, S., & Gamaat, S. (2015). Bilingual phonological awareness: Reexamining the evidence for relations within and across languages. *Journal of Educational Psychology*, *107*(1), 111–125. https://doi.org/10.1037/a0037149

Branum-Martin, L., Tao, S., Garnaat, S., Bunta, F., & Francis, D. J. (2012). Meta-analysis of bilingual phonological awareness: Language, age, and psycholinguistic grain size. *Journal of Educational Psychology*, *104*(4), 932–944. https://doi.org/10.1037/a0027755

Brysbaert, M., & New, B. (2009). Moving beyond Kučera and Francis: A critical evaluation of current word frequency norms and the introduction of a new and improved word frequency measure for American English. *Behavior Research Methods*, *41*(4), 977–990. https://doi.org/10.3758/BRM.41.4.977

Castles, A., & Coltheart, M. (2004). Is there a causal link from phonological awareness to success in learning to read?. *Cognition*, *91*(1), 77–111. https://doi.org/10.1016/s0010-0277(03)00164-1

Cohen-Gross, D. (2015). The syllable structure in the Modern Hebrew noun and adjective system. *Hebrew Studies*, *56*, 175–190.

De Cara, B., & Goswami, U. (2002). Statistical analysis of similarity relations among spoken words: Evidence for the special status of rimes in English. *Behavior Research Methods, Instruments, & Computers*, *34*, 416–423. https://doi.org/10.3758/BF03195470

Degani, T., Kreiner, H., Ataria, H., & Khateeb, F. (2020). The impact of brief exposure to the second language on native language production: Global or item specific?. *Applied Psycholinguistics*, *41*(1), 153–183. https://doi.org/10.1017/S0142716419000444

De Jong, P. F., & Van der Leij, A. (2003). Developmental changes in the manifestation of a phonological deficit in Dyslexic children learning to read a regular orthography. *Journal of Educational Psychology*, *95*(1), 22–40. https://doi.org/10.1037/0022-0663.95.1.22

De Rosario-Martinez, H. (2015). *phia: Post-hoc interaction analysis* (R package version 0.2-1). https://CRAN.R-project.org/package=phia

Durgunoğlu, A. Y., Nagy, W. E., & Hancin-Bhatt, B. J. (1993). Cross-language transfer of phonological awareness. *Journal of Educational Psychology*, *85*(3), 453–465. https://doi.org/10.1037/0022-0663.85.3.453

Elbro, C. (1996). Early linguistic abilities and reading development: A review and a hypothesis. *Reading and Writing*, *8*(6), 453–485.

Fowler, A. E. (1991). How early phonological development might set the stage for phoneme awareness. In S. A. Brady, & D. P. Shankweiler (Eds.), *Phonological processes in literacy: A tribute to Isabelle Y. Liberman* (pp. 97–117). Lawrence Erlbaum.

Geva, E., & Siegel, L. S. (2000). Orthographic and cognitive factors in the concurrent development of basic reading skills in two languages. *Reading and Writing*, *12*, 1–30. https://doi.org/10.1023/A:1008017710115

Gollan, T. H., Slattery, T. J., Goldenberg, D., Van Assche, E., Duyck, W., & Rayner, K. (2011). Frequency drives lexical access in reading but not in speaking: The frequency-lag hypothesis. *Journal of Experimental Psychology: General*, *140*(2), 186–209. https://doi.org/10.1037/a0022256

Gombert, J. E. (1992). *Metalinguistic development*. The University of Chicago Press.

Goswami, U. (2000). Phonological representations, reading development and dyslexia: Towards a cross-linguistic theoretical framework. *Dyslexia*, *6*(2), 133–151. https://doi.org/10.1002/(SICI)1099-0909(200004/06)6:2<133::AID-DYS160>3.0.CO;2-A

Goswami, U., Ziegler, J. C., & Richardson, U. (2005). The effects of spelling consistency on phonological awareness: A comparison of English and German. *Journal of Experimental Child Psychology*, *92*(4), 345–365. https://doi.org/10.1016/j.jecp.2005.06.002

Hoshino, N., & Kroll, J. F. (2008). Cognate effects in picture naming: Does cross-language activation survive a change of script?. *Cognition*, *106*(1), 501–511. https://doi.org/10.1016/j.cognition.2007.02.001

James, L. E., & Burke, D. M. (2000). Phonological priming effects on word retrieval and tip-of-the-tongue experiences in young and older adults. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *26*(6), 1378–1391. https://doi.org/10.1037/0278-7393.26.6.1378

Janssen, C., Segers, E., McQueen, J. M., & Verhoeven, L. (2017). Transfer from implicit to explicit phonological abilities in first and second language learners. *Bilingualism: Language and Cognition*, *20*(4), 795–812. https://doi.org/10.1017/S1366728916000523

Kavé, G. (2005). Phonemic fluency, semantic fluency, and difference scores: Normative data for adult Hebrew speakers. *Journal of Clinical and Experimental Neuropsychology*, *27*(6), 690–699. https://doi.org/10.1080/13803390490918499

Kilgarriff, A., Baisa, V., Bušta, J., Jakubíček, M., Kovář, V., Michelfeit, J., & Suchomel, V. (2014). The Sketch Engine: Ten years on. *Lexicography*, *1*, 7–36. https://doi.org/10.1007/s40607-014-0009-9

Kreiner, H., & Degani, T. (2015). Tip-of-the-tongue in a second language: The effects of brief first-language exposure and long-term use. *Cognition*, *137*, 106–114. https://doi.org/10.1016/j.cognition.2014.12.011

Kroll, J., & Gollan, T. (2014). Speech planning in two languages: What bilinguals tell us about speech production. In M. Goldarick, V. Ferreira, & M. Miozzo (Eds.), *The Oxford handbook of language production* (pp. 165–181). Oxford University press.

Kuo, L. J., & Anderson, R. C. (2010). Beyond cross-language transfer: Reconceptualizing the impact of early bilingualism on phonological awareness. *Scientific Studies of Reading*, *14*(4), 365–385. https://doi.org/10.1080/10888431003623470

Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2017). lmerTest package: Tests in linear mixed effects models. *Journal of Statistical Software*, *82*(13), 1–26. https://doi.org/10.18637/jss.v082.i13

Leather, C. V., & Henry, L. A. (1994). Working memory span and phonological awareness tasks as predictors of early reading ability. *Journal of Experimental Child Psychology*, *58*(1), 88–111. https://doi.org/10.1006/jecp.1994.1027

Marian, V., Blumenfeld, H. K., & Kaushanskaya, M. (2007). The Language Experience and Proficiency Questionnaire (LEAP-Q): Assessing language profiles in bilinguals and multilinguals. *Journal of Speech, Language, and Hearing Research*, *50*(4), 940–967. https://doi.org/10.1044/1092-4388(2007/067)

Morey, R. D. (2008). Confidence intervals from normalized data: A correction to Cousineau (2005). *Tutorial in Quantitative Methods for Psychology*, *4*(2), 61–64. https://doi.org/10.20982/tqmp.04.2.p06

Moriarty, B. C., & Gillon, G. T. (2006). Phonological awareness intervention for children with childhood apraxia of speech. *International Journal of Language & Communication Disorders*, *41*(6), 713–734. https://doi.org/10.1080/13682820600623960

Nation, K., & Snowling, M. J. (1998). Individual differences in contextual facilitation: Evidence from dyslexia and poor reading comprehension. *Child Development*, *69*(4), 996–1011. https://doi.org/10.1111/j.1467-8624.1998.tb06157.x

Nation, K., & Snowling, M. J. (2004). Beyond phonological skills: Broader language skills contribute to the development of reading. *Journal of Research in Reading*, *27*(4), 342–356. https://doi.org/10.1111/j.1467-9817.2004.00238.x

Navarra, J., Sebastián-Gallés, N., & Soto-Faraco, S. (2005). The perception of second language sounds in early bilinguals: New evidence from an implicit measure. *Journal of Experimental Psychology: Human Perception and Performance*, *31*(5), 912–918. https://doi.org/10.1037/0096-1523.31.5.912

Oakhill, J., & Kyle, F. (2000). The relation between phonological awareness and working memory. *Journal of Experimental Child Psychology*, *75*(2), 152–164. https://doi.org/10.1006/jecp.1999.2529

R Core Team. (2019). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. https://www.R–project.org/

Rohl, M., & Pratt, C. (1995). Phonological awareness, verbal working memory and the acquisition of literacy. *Reading and Writing*, *7*(4), 327–360. https://doi.org/10.1007/BF01027723

Russak, S., & Saiegh-Haddad, E. (2011). Phonological awareness in Hebrew (L1) and English (L2) in normal and disabled readers. *Reading and Writing*, *24*(4), 427–442. https://doi.org/10.1007/s11145-010-9235-1

Russak, S., & Saiegh-Haddad, E. (2017). Phonological awareness errors mirror underlying phonological representations: Evidence from Hebrew L1–English L2 adults. *Second Language Research*, *33*(4), 459–482. https://doi.org/10.1177/0267658317703682

Saiegh-Haddad, E. (2007a). Epilinguistic and metalinguistic phonological awareness may be subject to different constraints: Evidence from Hebrew. *First Language*, *27*(4), 385–405. https://doi.org/10.1177/0142723707081730

Saiegh-Haddad, E. (2007b). Linguistic constraints on children's ability to isolate phonemes in Arabic. *Applied Psycholinguistics*, *28*(4), 607–625. https://doi.org/10.1017/S0142716407070336

Saiegh-Haddad, E. (2019). What is phonological awareness in L2?. *Journal of Neurolinguistics*, *50*, 17–27. https://doi.org/10.1016/j.jneuroling.2017.11.001

Saiegh-Haddad, E., & Geva, E. (2008). Morphological awareness, phonological awareness, and reading in English–Arabic bilingual children. *Reading and Writing*, *21*, Article 481. https://doi.org/10.1007/s11145-007-9074-x

Saiegh-Haddad, E., Kogan, N., & Walters, J. (2010). Universal and language-specific constraints on phonemic awareness: Evidence from Russian–Hebrew bilingual children. *Reading and Writing*, *23*(3), 359–384. https://doi.org/10.1007/s11145-009-9204-8

Share, D. L., & Blum, P. (2005). Syllable splitting in literate and preliterate Hebrew speakers: Onsets and rimes or bodies and codas? *Journal of Experimental Child Psychology*, *92*(2), 182–202. https://doi.org/10.1016/j.jecp.2005.05.003

Simon, E., Sjerps, M. J., & Fikkert, P. (2014). Phonological representations in children's native and non-native lexicon. *Bilingualism: Language and Cognition*, *17*(1), 3–21. https://doi.org/10.1017/S1366728912000764

Swan, D., & Goswami, U. (1997). Phonological awareness deficits in developmental dyslexia and the phonological representations hypothesis. *Journal of Experimental Child Psychology*, *66*(1), 18–41. https://doi.org/10.1006/jecp.1997.2375

Tornéus, M. (1984). Phonological awareness and reading: A chicken and egg problem?. *Journal of Educational Psychology*, *76*(6), 1346–1358. https://doi.org/10.1037/0022-0663.76.6.1346

Treiman, R. (1985). Onsets and rimes as units of spoken syllables: Evidence from children. *Journal of Experimental Child Psychology*, *39*, 161–181. https://doi.org/10.1016/0022-0965(85)90034-7

Treiman, R., & Kessler, B. (1995). In defense of an onset–rime syllable structure for English. *Language and Speech*, *38*, 127–142. https://doi.org/10.1177/002383099503800201

Vellutino, F., & Scanlon, D. (1987). Phonological coding, phonological awareness, and reading ability: Evidence from a longitudinal and experimental Study. *Merrill-Palmer Quarterly*, *33*(3), 321–363.

Voeten, C. (2019). *buildmer: Stepwise elimination and term reordering for mixed-effects regression* (R package version 1.3). https://CRAN.R–project.org/package=buildmer

Wagensveld, B., Segers, E., van Alphen, P., & Verhoeven, L. (2013). The role of lexical representations and phonological overlap in rhyme judgments of beginning, intermediate and advanced readers. *Learning and Individual Differences*, *23*, 64–71. https://doi.org/10.1016/j.lindif.2012.09.007

Walley, A. C., Metsala, J. L., & Garlock, V. M. (2003). Spoken vocabulary growth: Its role in the development of phoneme awareness and early reading ability. *Reading and Writing*, *16*, 5–20. https://doi.org/10.1023/A:1021789804977

White, E. J., Titone, D., Genesee, F., & Steinhauer, K. (2017). Phonological processing in late second language learners: The effects of proficiency and task. *Bilingualism: Language and Cognition*, *20*(1), 162–183. https://doi.org/10.1017/S1366728915000620

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Einat Oz-Vecht is a speech and language pathologist working with families and children of diverse multilingual background.

Tamar Degani is a cognitive psychologist, studying multilingualism and second language learning. Her research examines the interplay among the different languages of multilingual speakers, and between language and cognition more broadly.

Appendix 1. Full list of auditory stimuli, presented here in IPA format.

Pair num	Language	Word1	Phonological structure	Word2	Phonological structure	Shared phon. structure	Basis for rhyme decision	Rhyme
1	English	dæns (dance)	cvcc	ˈeɪbəl (able)	vc.cc	Different	None	No
2	English	ˈɛvriˌwʌn (everyone)	c.ccv.cvc	wɜrld (world)	cvccc	Different	None	No
3	English	mɔr (more)	cvc	ˈʌðər (other)	c.cvc	Different	None	No
4	English	grin (green)	ccvc	fɑr (far)	cvc	Different	None	No
5	English	ˈɑləv (olive)	c.cvc	haʊs (house)	cvc	Different	None	No
6	English	pis (peace)	cvc	drim (dream)	ccvc	Different	None	No
7	English	flut (flute)	ccvc	ˈskærkroʊ (scarecrow)	ccvc.cvc	Different	None	No
8	English	ˈlɑʤɪk (logic)	cv.cvc	ˈprɛgnənsi (pregnancy)	ccvc.cvc.cv	Different	None	No
9	English	ˈkjukəmbər (cucumber)	cv.cvc.cvc	flʌd (flood)	ccvc	Different	None	No
10	English	mɛdəˈkeɪʃən (medication)	cv.cv.cv.cvc	ˈpɪriəd (period)	cv.cv.vc	Different	None	No
11	English	ˈfɔrhɛd (forehead)	cvc.cvc	ɪˈtɜrnəti (eternity)	c.cvc.cv.cv	Different	None	No
12	English	ˈpæˌspɔrt (passport)	cvc.cvcc	ˈrɛsəpi (recipe)	cv.cv.cv	Different	None	No
13	English	ˈʧænəl (channel)	cv.cvc	reɪs (race)	cvc	Different	None	No
14	English	ˈmʌŋki (monkey)	cvc.cv	drʌm (drum)	ccvc	Different	None	No
15	English	ˈmʌʃrum (mushroom)	cvc.cvc	ˈʌmˌbrɛlə (umbrella)	cv.ccv.cv	Different	None	No
16	English	dɔr (door)	cvc	ˈwɪndoʊ (window)	cvc.cvc	Different	None	No
17	English	ni (knee)	cv	ˈæŋkəl (ankle)	vc.cc	Different	None	No
18	English	glʌv (glove)	ccvc	koʊt (coat)	cvc	Different	None	No
19	English	ˈsɛntər (center)	cvc.cvc	ˈmɪdəl (middle)	cvcc	Different	None	No
20	English	ˈmʌˌstæʃ (mustache)	cvc.cvc	bɪrd (beard)	cvcc	Different	None	No
21	English	ˈprɪnsɛs (princess)	ccvc.cvc	ˈpæləs (palace)	cv.cvc	Different	None	No
22	English	rɔŋ (wrong)	ccvcc	mɪsˈteɪk (mistake)	cvc.cvc	Different	None	No
23	English	pɜrs (purse)	cvcc	bæg (bag)	cvc	Different	None	No
24	English	ˈtaʊəlz (towels)	cvcc	ʃits (sheets)	cvcc	Shared structure	None	No
25	English	ˈbɑrbər (barber)	cvc.cvc	hɛr (hair)	cvc	Different	None	No
26	English	ˈsʌmər (summer)	cv.cvc	sʌn (sun)	cvc	Different	None	No
27	English	noʊt (note)	cvc	peɪpər (paper)	cv.cvc	Different	None	No
28	English	ˈkaʊntər (counter)	cvccc.vc	bɑr (bar)	cvc	Different	None	No
29	English	roʊd (road)	cvc	træk (track)	ccvc	Different	None	No
30	English	geɪt (gate)	cvc	ˈbæriər (barrier)	cv.cv.vc	Different	None	No
31	English	ˈsɪzərz (scissors)	cv.cvcc	wil (wheel)	cvc	Different	None	No
32	English	ˈkæmərə (camera)	cv.cv.cv	pɪŋk (pink)	cvcc	Different	None	No
33	English	ˈɛləˌveɪtər (elevator)	c.cv.cv.cvc	keɪk (cake)	cvc	Different	None	No
34	English	ˈmuvi (movie)	cv.cv	drɔr (drawer)	ccvc	Different	None	No
35	English	skʌl (skull)	ccvc	ˈkɔlər (color)	cv.cvc	Different	None	No
36	English	roʊz (rose)	cvc	aɪ (eye)	vcv	Different	None	No
37	English	ˈnʌmbər (number)	cvc.cvc	tri (tree)	ccv	Different	None	No
38	English	ˈdɑkjəmɛnt (document)	cvc.cv.cvcc	ˈɔrənʤ (orange)	c.cvc.c	Different	None	No
39	English	ˈkærət (carrot)	cv.cvc	leɪk (lake)	cvc	Different	None	No
40	English	ˈfɪŋgər (finger)	cvc.cvc	ˈpinət (peanut)	cv.cvc	Different	None	No
41	English	fɪʃ (fish)	cvc	rɪŋ (ring)	cvcc	Different	None	No
42	English	græs (grass)	ccvc	ʤus (juice)	cvc	Different	None	No
43	English	ruf (roof)	cvc	sænd (sand)	cvcc	Different	None	No

(continued)

Appendix 1. (Continued)

Pair num	Language	Word1	Phonological structure	Word2	Phonological structure	Shared phon. structure	Basis for rhyme decision	Rhyme
44	English	ˈʌvən (oven)	c.cvc	ˈlɛtər (letter)	cv.cvc	Different	None	No
45	English	lʌŋz (lungs)	cvccc	flɔr (floor)	ccvc	Different	None	No
46	English	wɔl (wall)	cvc	bɔl (ball)	cvc	Shared structure	Partial syllable	Yes
47	English	ˈmɛˌdoʊ (meadow)	cv.cv	ˈɛlˌboʊ (elbow)	vc.cv	Different	Partial syllable	Yes
48	English	waɪz (wise)	cvc	raɪz (rise)	cvc	Shared structure	Whole syllable	Yes
49	English	dɪˈsɪʒən (decision)	cv.cv.cvc	priˈsɪʒən (precision)	ccv.cv.cvc	Different	Whole syllable	Yes
50	English	ɛg (egg)	vc	pɛg (peg)	cvc	Different	Partial syllable	Yes
51	English	hɛlθ (health)	cvcc	wɛlθ (wealth)	cvcc	Shared structure	Whole syllable	Yes
52	English	peɪs (pace)	cvc	treɪs (trace)	ccvc	Different	Partial syllable	Yes
53	English	meɪs (mace)	cvc	leɪs (lace)	cvc	Shared structure	Whole syllable	Yes
54	English	ˈprɛzɪdənt (president)	ccv.cv.cvcc	ˈrɛzɪdənt (resident)	cv.cv.cvcc	Different	Whole syllable	Yes
55	English	rɑk (rock)	cvc	mɑk (mock)	cvc	Shared structure	Partial syllable	Yes
56	English	tuθ (tooth)	cvc	buθ (booth)	cvc	Shared structure	Partial syllable	Yes
57	English	reɪ (ray)	cvc	beɪ (bay)	cvc	Shared structure	Partial syllable	Yes
58	English	ˈrɪvər (river)	cv.cvc	ˈfivər (fever)	cv.cvc	Shared structure	Whole syllable	Yes
59	English	ˈsɪlvər (silver)	cvc.cvc	ˈʃɪvər (shiver)	cv.cvc	Different	Whole syllable	Yes
60	English	goʊld (gold)	cvcc	moʊld (mold)	cvcc	Shared structure	Partial syllable	Yes
61	English	ʃild (shield)	cvcc	fild (field)	cvcc	Shared structure	Partial syllable	Yes
62	English	tɔɪ (toy)	cvc	ʤɔɪ (joy)	cvc	Shared structure	Partial syllable	Yes
63	English	smɛl (smell)	ccvc	bɛl (bell)	cvc	Different	Partial syllable	Yes
64	English	ˈbʌtər (butter)	cv.cvc	ˈkɑrtər (carter)	cvc.cvc	Different	Partial Syllable	Yes
65	English	ɪr (ear)	vc	tɪr (tear)	cvc	Different	Partial syllable	Yes
66	English	ˈfɔrɪst (forest)	cv.cvcc	ˈɑnəst (honest)	cv.cvcc	Shared structure	Partial syllable	Yes
67	English	brɪk (brick)	ccvc	nɪk (nick)	cvc	Different	Partial syllable	Yes
68	English	faɪt (fight)	cvc	raɪt (right)	cvc	Shared structure	Partial syllable	Yes
69	English	ˈmæʤɪk (magic)	cv.cvc	ˈfæbrɪk (fabric)	cvc.cvc	Different	Partial syllable	Yes
70	English	treɪl (trail)	ccvcc	teɪl (tail)	cvcc	Different	Partial syllable	Yes
71	English	læk (lack)	cvc	bæk (back)	cvc	Shared structure	Partial syllable	Yes
72	English	strɪŋ (string)	cccvcc	θɪŋ (thing)	cvcc	Different	Partial syllable	Yes
73	English	fɜr (fur)	cvc	slɜr (slur)	ccvc	Different	Partial syllable	Yes
74	English	mit (meat)	cvc	hit (heat)	cvc	Shared structure	Partial syllable	Yes
75	English	klaʊn (clown)	ccvc	braʊn (brown)	ccvc	Shared structure	Partial syllable	Yes
76	English	baʊnd (bound)	cvcc	saʊnd (sound)	cvcc	Shared structure	Whole syllable	Yes
77	English	praɪs (price)	ccvc	daɪs (dice)	cvc	Different	Whole syllable	Yes
78	English	ˈkændi (candy)	cvc.cv	ˈbændi (bandy)	cvc.cv	Shared structure	Whole syllable	Yes
79	English	dɪr (dear)	cvc	dɪr (fear)	cvc	Shared structure	Partial syllable	Yes
80	English	ˈsteɪpəl (staple)	ccvcc	ˈæmpəl (ample)	vccc	Different	Partial syllable	Yes
81	English	cumbrous (cumbrəs)	cvcc.cvc	ˈfeɪməs (famous)	cv.cvc	Different	Partial syllable	Yes
82	English	səˈblaɪm (sublime)	cvc.cvc	slaɪm (slime)	ccvc	Different	Whole syllable	Yes
83	English	grəˈneɪd (grenade)	ccv.cvc	prɑməˈneɪd (promenade)	ccv.cv.cvc	Different	Whole syllable	Yes
84	English	ˈfaɪər (fire)	cvc	ˈtaɪər (tire)	cvc	Shared structure	Whole syllable	Yes
85	English	kɪŋ (king)	cvcc	wɪŋ (wing)	cvcc	Shared structure	Partial syllable	Yes

(continued)

Appendix 1. (Continued)

Pair num	Language	Word1	Phonological structure	Word2	Phonological structure	Shared phon. structure	Basis for rhyme decision	Rhyme
86	English	skrin (screen)	cccvc	tin (teen)	cvc	Different	Partial syllable	Yes
87	English	blu (blue)	ccv	glu (glue)	ccv	Shared structure	Partial syllable	Yes
88	English	kɑr (car)	cvc	stɑr (star)	ccvc	Different	Partial syllable	Yes
89	English	fɔl (fall)	cvc	tɔl (tall)	cvc	Shared structure	Partial syllable	Yes
90	English	plet (plate)	ccvc	let (late)	cvc	Different	Whole syllable	Yes
91	Hebrew	(כלי) kli	ccv	(דואר) doʔaʁ	cv.vc	Different	None	No
92	Hebrew	(כתם) ketem	cv.cvc	(עגיל) ʔagil	c.cvc	Different	None	No
93	Hebrew	(פסל) pesel	cv.cvc	(מגרפה) magʁefa	cvc.cv.cv	Different	None	No
94	Hebrew	(נייר) nijaʁ	cv.cvc	(נחל) naxal	cv.cvc	Shared structure	None	No
95	Hebrew	(יומן) joman	cv.cvc	(קרנף) kaʁnaf	cvc.cvc	Different	None	No
96	**Hebrew**	**(צעיף) tsaʔif**	**cv.vc**	**(לפיד) lapid**	**cv.cvc**	**Different**	**None**	**No**
97	Hebrew	(ספה) sapa	cv.cv	(פרפר) paʁpaʁ	cvc.cvc	Different	None	No
98	Hebrew	(שכן) ʃaxen	cv.cvc	(סלט) salat	cv.cvc	Shared structure	None	No
99	Hebrew	(חנייה) xanaja	cv.cv.cv	(מנורה) menoʁʔa	cv.cv.cv	Shared structure	None	No
100	Hebrew	(אולר) ʔolaʁ	cv.cvc	(צמיד) tsamid	cv.cvc	Shared structure	None	No
101	**Hebrew**	**(עשב) ʔesev**	**c.cvc**	**(הגה) hege**	**cv.cv**	**Different**	**None**	**No**
102	Hebrew	(גביע) gaviʔa	cv.cv.c	(מראה) maʁʔa	cvc.c	Different	None	No
103	Hebrew	(מזלג) mazleg	cvc.cvc	(נמר) nameʁ	cv.cvc	Different	None	No
104	Hebrew	(מטען) matʔen	cvc.vc	(קערה) keʔaʁa	cv.c.cv	Different	None	No
105	Hebrew	(עיגול) ʔigul	c.cvc	(מחשב) maxʃev	cvc.cvc	Different	None	No
106	Hebrew	(מערה) meʔaʁa	cv.c.cv	(אמיץ) ʔamits	c.cvc	Different	None	No
107	Hebrew	(פסנתר) psanteʁ	ccvc.cvc	(שעג רה) har gaʔaʃ	cvc.cv.vc	Different	None	No
108	Hebrew	(בזבוז) bizbuz	cvc.cvc	(טעם) taʔam	cv.vc	Different	None	No
109	Hebrew	(שם) ʃem	cvc	(תהילה) tehila	cv.cv.cv	Different	None	No
110	Hebrew	(אויר) ʔaviʁ	c.cvc	(כסא) kise	cv.cv	Different	None	No
111	Hebrew	(מדף) madaf	cv.cvc	(עצמי) ʔatsmi	vc.cv	Different	None	No
112	Hebrew	(לחם) lexem	cv.cvc	(ראש) ʁoʃ	cvc	Different	None	No
113	Hebrew	(אורז) ʔoʁez	c.cvc	פעמיים paʔamaʔim	cv.c.cv.vc	Different	None	No
114	Hebrew	(עכברים) ʔaxbaʁim	cv.cv.cvc	(דמחנ) nexmad	cvc.cvc	Different	None	No
115	Hebrew	(טבח) tabax	cv.cvc	(כרס)keʁes	cv.cvc	Shared structure	None	No
116	Hebrew	(ציפור) tsipoʁ	cv.cvc	(שלישי) ʃliʃi	ccv.cv	Different	None	No
117	Hebrew	(חצאית) xatsaʔit	cv.cv.cvc	(לכלוך) lixlux	cvc.cvc	Different	None	No
118	Hebrew	(פרי) pʁri	ccv	(חליפה) xalifa	cv.cv.cv	Different	None	No
119	Hebrew	(רקמה) ʁikma	cvc.cv	(עניין) ʔinjan	cvc.cvc	Different	None	No
120	Hebrew	(חיוור) xiveʁ	cv.cvc	(אגדה) ʔagada	c.cv.cv	Different	None	No
121	Hebrew	(אצבע) ʔetsba	cvc.cv	(בוהן) bohen	cv.cvc	Different	None	No
122	**Hebrew**	**(במה) bama**	**cv.cv**	**(קהל) kahal**	**cv.cvc**	**Different**	**None**	**No**
123	Hebrew	(אוזניות) ʔoznijot	cvc.cv.cvc	(רמקול) ʁamkol	cvc.cvc	Different	None	No
124	Hebrew	(מקלדת) mikledet	cvc.cv.cvc	(מדפסת) madpeset	cvc.cv.cvc	Shared structure	Partial Syllable	No
125	**Hebrew**	**(חלק) xalak**	**cv.cvc**	**(ישר) jaʃaʁ**	**cv.cvc**	**Shared structure**	**None**	**No**
126	Hebrew	(מקל) makel	cv.cvc	(ענף) ʔanaf	c.cvc	Different	None	No
127	Hebrew	(רמזור)ʁamzoʁ	cvc.cvc	(תמרור) tamʁuʁ	cvc.cvc	Shared structure	None	No

(continued)

Appendix 1. (Continued)

Pair num	Language	Word1	Phonological structure	Word2	Phonological structure	Shared phon. structure	Basis for rhyme decision	Rhyme
128	Hebrew	(חור) xoʁ	cvc	(פתח) petax	cv.cvc	Different	None	No
129	Hebrew	(מנעול) manʔul	cvc.vc	(ידית) jadit	cv.cvc	Different	None	No
130	Hebrew	(מגב) magav	cv.cvc	(יעה) jaʔe	cv.vc	Different	None	No
131	**Hebrew**	**(גשם) geʃem**	**cv.cvc**	**(שלג) ʃeleg**	**cv.cvc**	**Shared structure**	**None**	**No**
132	**Hebrew**	**(מברגה) mavʁega**	**cvc.cv.cv**	**(מקדחה) makdexa**	**cvc.cv.cv**	**Shared structure**	**None**	**No**
133	**Hebrew**	**(אגס) ʔagas**	**c.cvc**	**(ענב) ʔanav**	**c.cvc**	**Shared structure**	**None**	**No**
134	Hebrew	(פרה) paʁa	cv.cv	(סוס) sus	cvc	Different	None	No
135	Hebrew	(מתוק) matok	cv.cvc	(מסטיק) mastik	cvc.cvc	Different	None	No
136	Hebrew	(עיתון) ʔiton	c.cvc	(שפתון) sfaton	ccv.cvc	Different	Whole syllable	Yes
137	Hebrew	(סוללה) solela	cv.cv.cv	(סלסלה) salsela	cvc.cv.cv	Different	Partial syllable	Yes
138	**Hebrew**	**(סגור) saguʁ**	**cv.cvc**	**(עגור) ʔaguʁ**	**c.cvc**	**Different**	**Whole syllable**	**Yes**
139	Hebrew	(חופשי) xofʃi	cvc.cv	(נפשי) nafʃi	cvc.cv	Shared structure	Whole syllable	Yes
140	Hebrew	(ערוגה) ʔaʁuga	c.cv.cv	(הפוגה) hafuga	c.cv.cv	Shared structure	Whole syllable	Yes
141	Hebrew	(ילדות) jaldut	cv.cv.cvc	(נדנדות) nadnedot	cvc.cv.cvc	Different	Whole syllable	Yes
142	Hebrew	(ינשוף) janʃuf	cvc.cvc	(כישוף) kiʃuf	cv.cvc	Different	Whole syllable	Yes
143	**Hebrew**	**(תנומה) tnuma**	**ccv.cv**	**(תקומה) tkuma**	**ccv.cv**	**Shared structure**	**Whole syllable**	**Yes**
144	Hebrew	(חרוז) xaʁuz	cv.cvc	(תפוז) tapuz	cv.cvc	Shared structure	Partial syllable	Yes
145	Hebrew	(מילה) mila	cv.cv	(פילה) pila	cv.cv	Shared structure	Syllable +	Yes
146	Hebrew	(מאדים) maʔadim	cv.c.cvc	(כדים) kadim	cv.cvc	Different	Whole syllable	Yes
147	Hebrew	(משרוקית) maʃʁokit	cvc.cv.cvc	(איטלקית) ʔitalkit	c.cvc.cvc	Different	Whole syllable	Yes
148	Hebrew	(כלנית) kalanit	cv.cv.cvc	(חילונית) xilonit	cv.cv.cvc	Shared structure	Whole syllable	Yes
149	Hebrew	(מזגן) mazgan	cvc.cvc	(מאורגן) meʔuʁgan	cv.vc.cvc	Different	Whole syllable	Yes
150	**Hebrew**	**(כפילה) kfila**	**ccv.cv**	**(תפילה)tfila**	**ccv.cv**	**Shared structure**	**Syllable +**	**Yes**
151	Hebrew	(מסלול) maslul	cvc.cvc	(שבלול) ʃablul	cvc.cvc	Shared structure	Whole syllable	Yes
152	**Hebrew**	**(יער) jaʔaʁ**	**cv.cv**	**(שער) ʃaʔaʁ**	**cv.cv**	**Shared structure**	**Whole syllable**	**Yes**
153	**Hebrew**	**(ערב) ʔeʁev**	**c.cvc**	**(גרב) geʁev**	**cv.cvc**	**Different**	**Whole syllable**	**Yes**
154	Hebrew	(ערפל) ʔaʁafel	c.cv.cvc	(תפל) tafel	cv.cvc	Different	Partial syllable	Yes
155	**Hebrew**	**(פטיש) patiʃ**	**cv.cvc**	**(קשיש) kaʃiʃ**	**cv.cvc**	**Shared structure**	**Whole syllable**	**Yes**
156	**Hebrew**	**(צילום) tsilum**	**cv.cvc**	**(דקלום) diklum**	**cvc.cvc**	**Different**	**Whole syllable**	**Yes**
157	Hebrew	(כישרון) kiʃʁon	cv.cv.cvc	(אחרון) ʔaxaʁon	c.cv.cvc	Different	Whole syllable	Yes
158	Hebrew	(תאנה) teʔena	cv.c.cv	(פנינה) pnina	ccv.cv	Different	Partial syllable	Yes
159	Hebrew	(בובה) buba	cv.cv	(דובה) duba	cv.cv	Shared structure	Whole syllable	Yes
160	Hebrew	(עריסה) ʔaʁisa	c.cv.cv	(לעיסה) leʔisa	cv.c.cv	Different	Whole syllable	Yes
161	**Hebrew**	**(שמיכה) smixa**	**ccv.cv**	**(בריחה) bʁixa**	**ccv.cv**	**Shared structure**	**Whole syllable**	**Yes**
162	**Hebrew**	**(ספר) sefeʁ**	**cv.cvc**	**(תפר) tefeʁ**	**cv.cvc**	**Shared structure**	**Syllable +**	**Yes**
163	**Hebrew**	**(שקע) ʃeka**	**cv.cv**	**(נקע)neka**	**cv.cv**	**Shared structure**	**Whole syllable**	**Yes**
164	**Hebrew**	**(קציר) katsiʁ**	**cv.cvc**	**(עציר) ʔatsiʁ**	**c.cvc**	**Different**	**Whole syllable**	**Yes**
165	**Hebrew**	**(חולצה) xultsa**	**cvc.cv**	**(אומצה) ʔumtsa**	**cvc.cv**	**Shared structure**	**Whole syllable**	**Yes**
166	Hebrew	(גלים) galim	cv.cvc	(כלים) kelim	cv.cvc	Shared structure	Whole syllable	Yes

(continued)

Appendix 1. (Continued)

Pair num	Language	Word1	Phonological structure	Word2	Phonological structure	Shared phon. structure	Basis for rhyme decision	Rhyme
167	Hebrew	(ליצן) lejtsan	cvc.cvc	(חרצן) xaʁtsan	cvc.cvc	Shared structure	Whole syllable	Yes
168	**Hebrew**	**(פרח) peʁax**	**cv.cvc**	**(קרח) keʁax**	**cv.cvc**	**Shared structure**	**Syllable +**	**Yes**
169	**Hebrew**	**(איפור) ʔipuʁ**	**v.cvc**	**(סיפור) sipuʁ**	**cv.cvc**	**Shared structure**	**Whole syllable**	**Yes**
170	**Hebrew**	**(ארון) ʔaʁon**	**v.cvc**	**(גרון) gaʁon**	**cv.cvc**	**Shared structure**	**Whole syllable**	**Yes**
171	Hebrew	(להקה) lehaka	cv.cv.cv	(העמקה) haʔamaka	cv.v.cv.cv	Different	Whole syllable	Yes
172	Hebrew	(שלט) ʃelet	cv.cvc	(פלט) pelet	cv.cvc	Shared structure	Syllable +	Yes
173	Hebrew	(בקבוק) bakbuk	cvc.cvc	(חיבוק) xibuk	cv.cvc	Different	Whole syllable	Yes
174	**Hebrew**	**(תחתית) taxtit**	**cvc.cvc**	**(תשתית) taʃtit**	**cvc.cvc**	**Shared structure**	**Whole syllable**	**Yes**
175	Hebrew	(אווירון) ʔaviʁon	v.cv.cvc	(עיפרון) ʔipaʁon	v.cv.cvc	Shared structure	Whole syllable	Yes
176	Hebrew	(קלמר) kalmaʁ	cvc.cvc	(נגמר) nigmaʁ	cvc.cvc	Shared structure	Whole syllable	Yes
177	Hebrew	(גינה) gina	cv.cv	(גבינה) gvina	ccv.cv	Different	Whole syllable	Yes
178	Hebrew	(ארוחה) ʔaʁuxa	v.cv.cv	(משפחה) miʃpaxa	cvc.cv.cv	Different	Whole syllable	Yes
179	**Hebrew**	**(שולחן) ʃulxan**	**cvc.cvc**	**(פולחן) pulxan**	**cvc.cvc**	**Shared structure**	**Syllable +**	**Yes**
180	Hebrew	(עבדות) ʔavdut	vc.cvc	(כבדות) kvedut	ccv.cvc	Shared structure	Whole syllable	Yes
181	Pseudo-Hebrew	ko	cv	dix	cvc	Different	None	No
182	Pseudo-Hebrew	mo	cv	leʁ	cvc	Different	None	No
183	Pseudo-Hebrew	pintab	cvc.cvc	funʁes	cvc.cvc	Shared structure	None	No
184	Pseudo-Hebrew	bisaf	cv.cvc	fofem	cv.cvc	Shared structure	None	No
185	Pseudo-Hebrew	kanak	cv.cvc	lopal	cv.cvc	Shared structure	None	No
186	Pseudo-Hebrew	tre	ccv	los	cvc	Different	None	No
187	Pseudo-Hebrew	mosu	cv.cv	zinxa	cvc.cv	Different	None	No
188	Pseudo-Hebrew	rowas	cv.cvc	moper	cv.cvc	Shared structure	None	No
189	Pseudo-Hebrew	lega	cv.cv	təlx	cvcc	Different	None	No
190	Pseudo-Hebrew	madʒ	cvc	taʔin	cv.vc	Different	None	No
191	Pseudo-Hebrew	niaʃ	cv.vc	nadʒim	cvcc.vc	Different	None	No
192	Pseudo-Hebrew	ʔelel	c.cvc	bivdal	cvc.cvc	Different	None	No
193	Pseudo-Hebrew	ʔembadʒ	cv.cvc	jazu	cv.cv	Different	None	No
194	Pseudo-Hebrew	oik	cvc	lawʁ	cvcc	Different	None	No
195	Pseudo-Hebrew	lepe	cv.cv	nadʒi	cv.cv	Shared structure	None	No
196	Pseudo-Hebrew	ru	cv	wa	cv	Shared structure	None	No
197	Pseudo-Hebrew	xel	cvc	gak	cvc	Shared structure	None	No
198	Pseudo-Hebrew	tupasti	cv.cvc.cv	xapisash	cv.cv.cvc	Different	None	No
199	Pseudo-Hebrew	tuklai	cv.ccvc	ʁemekeli	cv.cv.cv.cv	Different	None	No
200	Pseudo-Hebrew	awatmi	c.cvc.cv	bertas	cvc.cvc	Different	None	No
201	Pseudo-Hebrew	daʔir	cv.vc	haiz	cv.vc	Shared structure	None	No
202	Pseudo-Hebrew	ʔiʔunab	c.c.cvc	metudem	cv.cv.cvc	Different	None	No
203	Pseudo-Hebrew	tutseriv	cvc.cv.cvc	ʔoplaseg	cv.cv.cvc	Different	None	No
204	Pseudo-Hebrew	tkikol	ccv.cvc	ʔutril	cv.cvc	Different	None	No
205	Pseudo-Hebrew	shertan	cvc.cvc	tioprai	cv.vc.cvc	Different	None	No

(continued)

Appendix 1. (Continued)

Pair num	Language	Word1	Phonological structure	Word2	Phonological structure	Shared phon. structure	Basis for rhyme decision	Rhyme
206	Pseudo-Hebrew	ʔuilts	cv.ccc	ʔoftsa	vc.ccv	Different	None	No
207	Pseudo-Hebrew	ʔigmax	cv.cvc	jesli	cvc.cv	Different	None	No
208	Pseudo-Hebrew	agfe	vc.cv	nalde	cvc.cv	Different	None	No
209	Pseudo-Hebrew	ʔoreʔik	c.cv.vc	ʔutale	c.cv.cv	Different	None	No
210	Pseudo-Hebrew	sadi	cv.cv	ʔupas	c.cvc	Different	None	No
211	Pseudo-Hebrew	tiglo	cvc.cv	musda	cvc.cv	Shared structure	None	No
212	Pseudo-Hebrew	mene	cv.cv	rawi	cv.cv	Shared structure	None	No
213	Pseudo-Hebrew	ʔetab	v.cvc	gemva	cvc.vc	Different	None	No
214	Pseudo-Hebrew	koshar	cv.cvc	nasil	cv.cvc	Shared structure	None	No
215	Pseudo-Hebrew	ʔunma	cv.cv	lada	cv.cv	Shared structure	None	No
216	Pseudo-Hebrew	ʔoptux	cv.cvc	kuxma	cvc.cv	Different	None	No
217	Pseudo-Hebrew	rig	cvc	dʒat	cvc	Shared structure	None	No
218	Pseudo-Hebrew	navu	cv.cv	xes	cvc	Different	None	No
219	Pseudo-Hebrew	absi	cv.cv	lopʁa	cvc.cv	Different	None	No
220	Pseudo-Hebrew	keg	cvc	daz	cvc	Shared structure	None	No
221	Pseudo-Hebrew	flmk	cccc	iʁank	ccvcc	Different	None	No
222	Pseudo-Hebrew	gunje	cvc.cv	kewawe	cv.cv.cv	Different	None	No
223	Pseudo-Hebrew	lagevi	cv.cv.cv	baxti	cvc.cv	Different	None	No
224	Pseudo-Hebrew	gerulanam	cv.cv.cv.cvc	dunabaz	cv.cv.cvc	Different	None	No
225	Pseudo-Hebrew	nidsa	cvc.vc	fisga	cvc.vc	Shared structure	Partial syllable	No
226	Pseudo-Hebrew	gasr	cvcc	tasr	cvcc	Shared structure	Partial syllable	Yes
227	Pseudo-Hebrew	klivs	ccvcc	owʁivs	vccvcc	Different	Partial syllable	Yes
228	Pseudo-Hebrew	dageʁ	cv.cvc	vatgeʁ	cvc.cvc	Different	Whole syllable	Yes
229	Pseudo-Hebrew	ghib	ccvc	saxhib	cvc.cvc	Different	Whole syllable	Yes
230	Pseudo-Hebrew	tiyad	cv.cvc	veoyad	cv.v.cvc	Different	Whole syllable	Yes
231	Pseudo-Hebrew	gamta	cvc.cv	ramta	cvc.cv	Shared structure	Whole syllable	Yes
232	Pseudo-Hebrew	duf	cvc	yuf	cvc	Shared structure	Partial syllable	Yes
233	Pseudo-Hebrew	tsemo	ccv.cv	hemo	cv.cv	Different	Whole syllable	Yes
234	Pseudo-Hebrew	ʃdʒi	ccv	mdʒi	ccv	Shared structure	Partial syllable	Yes
235	Pseudo-Hebrew	xifad	cv.cvc	gefad	cv.cvc	Shared structure	Whole syllable	Yes
236	Pseudo-Hebrew	ʔamflu	vc.ccv	deʔaflu	cv.v.ccv	Different	Whole syllable	Yes
237	Pseudo-Hebrew	sase	cv.cv	nise	cv.cv	Shared structure	Partial syllable	Yes
238	Pseudo-Hebrew	linl	cvcc	minl	cvcc	Shared structure	Partial syllable	Yes
239	Pseudo-Hebrew	lomesal	cv.cv.cvc	womesal	cv.cv.cvc	Shared structure	Syllable +	Yes
240	Pseudo-Hebrew	fafli	cvc.cv	bendli	cvcc.cv	Different	Partial syllable	Yes
241	Pseudo-Hebrew	pexbes	cvc.cvc	kigbes	cvc.cvc	Shared structure	Whole syllable	Yes
242	Pseudo-Hebrew	ʃesʁab	cvc.cvc	lobʁab	cvc.cvc	Shared structure	Whole syllable	Yes
243	Pseudo-Hebrew	ʔaʁe	c.cv	zizaʁe	cv.cv.cv	Different	Whole syllable	Yes
244	Pseudo-Hebrew	toyo	cv.cv	lofyo	cvc.cv	Different	Partial syllable	Yes
245	Pseudo-Hebrew	lole	cv.c	fotle	cvc.cv	Different	Partial syllable	Yes
246	Pseudo-Hebrew	lulen	cv.cvc	duglen	cvc.cvc	Different	Whole syllable	Yes

(continued)

Appendix 1. (Continued)

Pair num	Language	Word1	Phonological structure	Word2	Phonological structure	Shared phon. structure	Basis for rhyme decision	Rhyme
247	Pseudo-Hebrew	nadʁie	cvc.cv	kimaʁie	cv.cv.cv	Different	Whole syllable	Yes
248	Pseudo-Hebrew	poʁxa	cvc.cv	ʃudxa	cvc.cv	Shared structure	Partial syllable	Yes
249	Pseudo-Hebrew	dekvam	cvc.cvc	fivam	cv.cvc	Different	Whole syllable	Yes
250	Pseudo-Hebrew	ʃug	cvc	lug	cvc	Shared structure	Partial syllable	Yes
251	Pseudo-Hebrew	ayo	c.cv	bayo	cv.cv	Different	Whole syllable	Yes
252	Pseudo-Hebrew	binteʔa	cvc.cv.v	milteʔa	cvc.cv.v	Shared structure	Whole syllable	Yes
253	Pseudo-Hebrew	obabi	vcv.cv	kigabi	cvcv.cv	Shared structure	Syllable +	Yes
254	Pseudo-Hebrew	keg	cvc	seg	cvc	Shared structure	Partial syllable	Yes
255	Pseudo-Hebrew	naʔozi	cv.vcv	bakozi	cv.cv.cv	Different	Whole syllable	Yes
256	Pseudo-Hebrew	forx	cvcc	borx	cvcc	Shared structure	Partial syllable	Yes
257	Pseudo-Hebrew	gisev	cv.cvc	lasev	cv.cvc	Shared structure	Whole syllable	Yes
258	Pseudo-Hebrew	mətikato	cv.cv.cv.cv	difirato	cv.cv.cv.cv	Shared structure	Whole syllable	Yes
259	Pseudo-Hebrew	dase	cv.cv	fase	cv.cv	Shared structure	Whole syllable	Yes
260	Pseudo-Hebrew	yurubp	cvc	rup	cvc	Shared structure	Partial syllable	Yes
261	Pseudo-Hebrew	gidʒmaz	cvc.cvc	klewamaz	ccv.cv.cvc	Different	Whole syllable	Yes
262	Pseudo-Hebrew	lopk	cvcc	opk	vcc	Different	Whole syllable	Yes
263	Pseudo-Hebrew	gvli	cccv	sakvli	cvc.ccvc	Different	Whole syllable	Yes
264	Pseudo-Hebrew	fafaba	cv.cv.cv	wesabɑ	cv.cv.cv	Shared structure	Partial syllable	Yes
265	Pseudo-Hebrew	krtu	cccv	srtu	cccv	Shared structure	Whole syllable	Yes
266	Pseudo-Hebrew	nilɑ	cv.cv	dilɑ	cv.cv	Shared structure	Whole syllable	Yes
267	Pseudo-Hebrew	etvik	cvc.cvc	bnvik	c.ccvc	Different	Whole syllable	Yes
268	Pseudo-Hebrew	dʒisfag	cvc.cvc	kizfɑg	cvc.cvc	Shared structure	Whole syllable	Yes
269	Pseudo-Hebrew	mɑʃʁuk	cvc.cvc	sunbʁuk	cvc.ccvc	Different	Whole syllable	Yes
270	Pseudo-Hebrew	mɑgvev	cvc.cvc	bɑlvev	cvc.cvc	Shared structure	Whole syllable	Yes

Note: Bolded pairs are the Hebrew and pseudo-Hebrew pairs that share a morphological pattern across the two words in the pair.

Appendix 2

List matching Experiment 1b

Table 5. List characteristics by language.

	Word type					
	English pairs		Hebrew pairs		Pseudo-Hebrew pairs	
	List 1	List 2	List 1	List 2	List 1	List 2
Number of pairs	45	45	45	45	45	45
Average number of syllables	1.53 (.65)	1.42 (.54)	2.19 (.40)	2.22 (.42)	1.94 (.75)	1.97 (.58)
Averaged item frequency	108.85 (320.32)	105.70 (208.86)	32.02 (43.69)	33.39 (83.16)	N/A	N/A
Part of speech (% noun)	92.2%	85.6%	90.0%	85.5%	N/A	N/A

*Note: SD*s appear in parentheses. Within each language, there were no significant differences between the two lists at the level of $p < .05$. For Experiment 1b, only List 1 ($n = 135$) administered pre-exposure is analyzed and compared to the first 135 trials randomly sampled from the full set (i.e., combination of Lists 1 and 2) of Experiment 1a.

Appendix 3

Analysis on RT data without outlier removal

Long-term modulations—English-Hebrew versus Hebrew-English bilinguals. Raw reaction time (RT) (without trimming of trials more than 2.5 *SD*s from each participant's mean correct response) was log-transformed prior to analysis to remove skew in the distribution. The analyses of these logRT revealed that RTs decreased with average syllable length. Of relevance, there were main effects for Response and Type that were qualified by two-way interactions between Response and Type, Response and Group, and critically Type and Group (see Table 6 from the Anova function and Table 7 from the *summary* function of the selected model). RTs were slower for 'yes' responses, and this was more pronounced for pseudo-Hebrew words. Furthermore, the difference was larger for English-Hebrew bilinguals. Most critically, follow-up tests with Bonferroni corrections for multiple comparisons reveal that in both participant groups, responses were equally fast for Hebrew and English pairs, which were both faster than responses to pseudo-Hebrew pairs (see Figure 4).

Table 6. Anova summary of the model predicting log RT data.

Log RTs (ms) on correct responses					
Fixed effects	*MSS*	Num. *df*	Den. *df*	*F*-value	*p*-value
(normalized) Syll	0.38	1	63	3.99	.050±
Response	2.65	1	136	27.84	<.000***
Group	0.13	1	65	1.39	.243
Type	1.53	2	241	16.04	<.000***
Type × Response	1.10	2	246	11.51	<.000***
Group × Response	0.39	1	74	4.05	.048*
Type × Group	0.32	2	4325	3.31	.037*

RT: reaction time.
± p <0.1; * $p < .05$; *** $p < 0.001$.

Table 7. Summary of the selected model predicting log RT.

Log RTs (ms) on correct responses					
Fixed effects	Estimate	*SE*	*df*	*t*-value	*p*-value
(Intercept)	2.38	0.05	74.10	44.31	<.001***
(normalized) Syll	−0.10	0.05	62.66	−2.00	.050±
Response (Yes)	0.08	0.02	231.78	3.18	.002**
Group (HE)	0.17	0.11	64.57	1.64	.106
Type (Hebrew)	0.04	0.02	315.88	1.80	.072±
Type (Pseudo)	0.03	0.02	312.96	1.50	.135
Type (Hebrew) × Response (Yes)	−0.04	0.03	244.11	−1.27	.207
Type (Pseudo) × Response (yes)	0.10	0.03	246.81	3.38	.001***
Group (HE) × Response (yes)	−0.05	0.02	73.80	−2.01	.048*
Type (Hebrew) × Group (HE)	−0.05	0.02	4366.04	−2.57	.010*
Type (Pseudo) × Group (HE)	−0.03	0.02	4174.86	−1.32	.186

(Continued)

Table 7. (Continued)

Random effects	Variance (*SD*)	
	Intercept	Slope
Participant	0.01 (0.12)	0.004 (0.07)
Item	0.01 (0.07)	
Residual	0.10 (0.31)	

RT: reaction time; HE: Hebrew-English; EH: English-Hebrew.
Selected Model: buildmer(logRT~(1 + Response|Subject) + (1|ItemID) + SyllableLength + (Group + Response + Type)[2], data = BISRHRT, ddf = "Satterthwaite," REML = FALSE, control = lmerControl(optimizer = "bobyqa"), calc.anova = TRUE, calc.summary = TRUE).
± p <0.1; * $p < .05$; ** $p < .01$; ***$p < 0.001$.

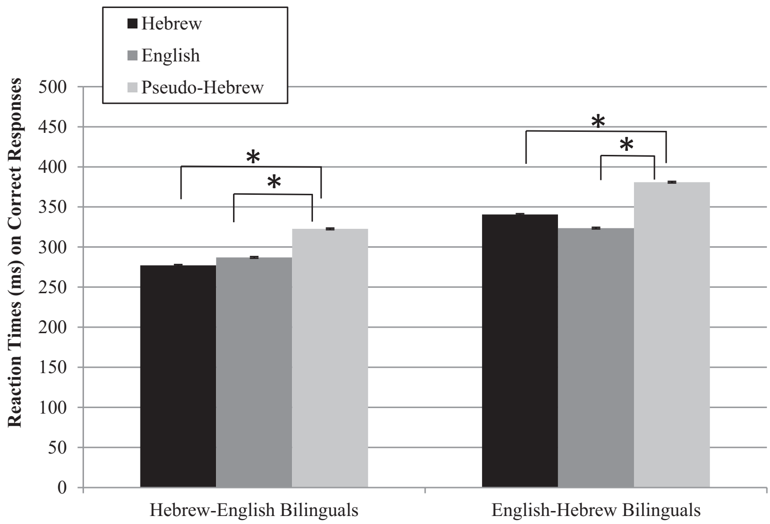

Figure 4. Estimated reaction times (without cleaning) on correct responses in the rhyme judgment task as a function of group and pair type (error bars represent *SE* calculated for within-participant variables following Morey, 2008).

Appendix 4

Selected model summary predicting RT comparing both groups and multiple comparisons

Table 8. Summary table for the selected model predicting reaction time comparing English-Hebrew to Hebrew-English (HE).

Clean reaction times (ms) on correct responses					
Fixed effects	Estimate	*SE*	*df*	*t*-value	*p*-value
(Intercept)	226.61	26.10	65.44	8.68	<.001***
(normalized) Age	24.14	8.11	62.10	2.98	<.001**
Type (Hebrew)	15.32	6.36	6,792.56	2.41	.02*
Type (Pseudo)	21.43	6.35	6,792.75	3.37	<.001***
(normalized) Syllable length	−68.32	25.75	62.32	−2.65	.018*

(Continued)

Table 8. (Continued)

Group (HE)	136.55	52.97	63.47	2.58	.01*
Response (yes)	10.08	6.14	6,793.38	1.64	.10
Type (Hebrew) × Response (yes)	5.98	7.52	6,793.46	0.80	.43
Type (Pseudo) × Response (yes)	37.91	7.71	6,793.65	4.92	<.001***
Group (HE) × Response (yes)	−15.28	6.25	6,797.42	−2.45	.01*
Type (Hebrew) × Group (HE)	−20.71	7.52	6,793.92	−2.75	.01**
Type (Pseudo) × Group (HE)	−6.82	7.68	6,793.90	−0.89	.37
Random effects	Variance (*SD*)				
	Intercept				Slope
Participant	3,332 (57.72)				
Residual	16,431 (128.18				

Selected Model: buildmer(RT~(1|Subject) + Age + SyllableLength + (Group + Response + Type)^2, data = BISRHRT, ddf = "Satterthwaite," REML = FALSE, control = lmerControl(optimizer = "bobyqa"), calc.anova = TRUE, calc.summary = TRUE).
* $p < .05$; ** $p < .01$; *** $p < 0.001$.

Table 9. Pairwise comparisons with Bonferroni corrections for multiple comparisons.

Pairwise comparison	Fixed level	Value	*df*	χ^2	*p*-value
No–yes	English	−2.44	1	0.21	1.00
No–yes	Hebrew	−8.42	1	2.53	.33
No–yes	Pseudo	−40.35	1	52.66	<.001***
No–yes	EH	−24.71	1	31.79	<.001***
No–yes	HE	−9.43	1	4.48	.069 ±
EH–HE	English	−128.91	1	5.95	.044*
EH–HE	Hebrew	−108.19	1	4.19	.122
EH–HE	Pseudo	−122.09	1	5.33	.063±
English–Hebrew	EH	−18.32	1	12.23	.003**
English–Pseudo	EH	−40.38	1	56.01	<.001***
Hebrew–Pseudo	EH	−22.07	1	16.81	<.001***
English–Hebrew	HE	2.40	1	0.20	1.00
English–Pseudo	HE	−33.57	1	37.41	<.001***
Hebrew–Pseudo	HE	−35.97	1	43.61	<.001***
English–Hebrew	No–EH	−15.32	1	5.80	.193
English–Pseudo	No–EH	−21.43	1	11.38	.009**
Hebrew–Pseudo	No–EH	−6.10	1	0.91	1.000
English–Hebrew	Yes–EH	−21.31	1	10.64	.013*
English–Pseudo	Yes–EH	−59.34	1	73.94	<.001***
Hebrew–Pseudo	Yes–EH	−38.03	1	31.14	<.001***
English–Hebrew	No–EH	5.39	1	0.69	1.000
English–Pseudo	No–HE	−14.61	1	4.99	.305
Hebrew–Pseudo	No–HE	−20.00	1	9.32	.027*
English–Hebrew	Yes–HE	−0.59	1	0.01	1.000
English–Pseudo	Yes–HE	−52.52	1	58.42	<.001***
Hebrew–Pseudo	Yes–HE	−51.93	1	58.91	<.001***

HE: Hebrew-English; EH: English-Hebrew.
± $p < 0.1$; * $p < .05$; ** $p < .01$; *** $p < 0.001$.

Appendix 5

Error rate analyses comparing both groups

Error rates were analyzed following a binomial distribution (i.e., mixed logistic regression), and model building strategy was identical to that reported for the RT analyses. The error rate analyses revealed that correct 'yes' responses were significantly more error prone than 'no' responses (see Tables 10 and 11). In addition, frequency (normalized within each language) exerted a significant effect, such that increased frequency was associated with fewer errors. Furthermore, there was a significant interaction between Type and Group (see Figure 5). Follow-up tests with Bonferroni corrections (see Table 12) revealed, however, that the differences among the pair types did not reach significance in either group. Results remained the same when frequency was not controlled for in this analysis.

Table 10. Selected model summary predicting error rates for the first part of the task (135 items).

Error rates				
Fixed effects	*df*	*MSS*	*F*-value	*p*-value
Response	1	25.91	25.91	<.001***
z-frequency	1	7.99	7.99	.005**
Group	1	2.73	2.73	.10
Type	2	1.24	1.24	.54
Response × Type	2	3.15	3.15	.21
Type × Group	2	6.01	6.01	.05*

± p <0.1; ** $p < .01$; *** $p < 0.001$.

Table 11. Summary table for the selected model predicting error rate comparing English-Hebrew to Hebrew-English.

Error rate (ms) on correct responses				
Fixed effects	Estimate	*SE*	z-value	*p*-value
(Intercept)	−7.75	0.76	−10.26	<.001***
Response (yes)	2.43	0.70	3.48	.001***
zFrequency	−0.55	0.33	−1.68	.093±
Group (HE)	1.79	0.63	2.86	.004**
Type (Hebrew)	2.01	0.84	2.38	.017*
Type (Pseudo)	0.10	0.90	0.11	.912
Response (yes)	−0.99	0.86	−1.15	.249
Type (Hebrew) × Response (yes)	1.49	0.85	1.75	.080±
Type (Pseudo) × Response (yes)	−2.39	0.67	−3.59	<.001***
Type (Hebrew) × Group (HE)	−1.24	0.63	−1.96	.050±
Type (Pseudo) × Group (HE)	−7.75	0.76	−10.26	<.001***

Random effects	Variance (*SD*)	
	Intercept	Slope
Participant	1.07 (1.04)	4.78 (2.19)
Item	6.42 (2.55)	2.75 (1.66)

± p <0.1; ** $p < .01$; *** $p < 0.001$.

Table 12. Pairwise comparisons with Bonferroni corrections for multiple comparisons of the error rate data.

Pairwise comparison	Fixed level	Value	*df*	χ^2	*p*-value
No–yes	English	0.08	1	12.07	.002**
No–yes	Hebrew	0.19	1	4.08	.13
No–yes	Pseudo	0.02	1	29.86	<.001***
EH–HE	English	0.14	1	8.16	.013*
EH–HE	Hebrew	0.64	1	1.04	.92
EH–HE	Pseudo	0.37	1	1.16	.85
English–Hebrew	EH	0.18	1	5.06	.15
English–Pseudo	EH	0.30	1	1.28	1.00
Hebrew–Pseudo	EH	0.66	1	0.90	1.00
English–Hebrew	HE	0.71	1	3.69	.33
English–Pseudo	HE	0.60	1	0.55	1.00
Hebrew–Pseudo	HE	0.38	1	0.76	1.00

± p <0.1; * $p < .05$; ** $p < .01$;*** p <0.001.

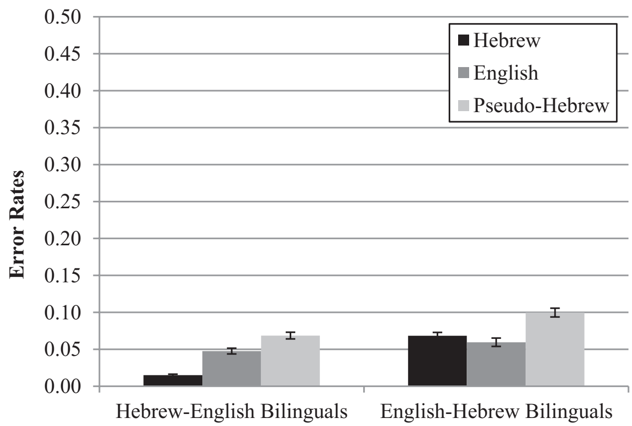

Figure 5. Estimated error rates in the rhyme judgment task as a function of group and pair type (error bars represent *SE* calculated for within-participant variables following Morey, 2008).

Appendix 6

Brief exposure effect within the English-Hebrew bilinguals tested in Experiment 1b

These analyses include 33 English-Hebrew bilinguals tested in Experiment 1b, predicting performance in the rhyme judgment task as a function of Response (No vs Yes), Pair Type (English, Hebrew, pseudo-Hebrew), Time (pre- vs post-exposure) and Condition (Control non-linguistic vs Experimental English movie). The effect of interest was an interaction between Time and Condition, but the effect of Time and its interaction with Condition did not survive model comparisons.

Table 13. Summary table for the selected model predicting RT comparing experimental and control among English-Hebrew bilinguals.

Clean reaction times (ms) on correct responses					
Fixed effects	Estimate	*SE*	*df*	*t*-value	*p*-value
(Intercept)	337.91	17.84	47.97	18.94	<.001***
Type (Hebrew)	13.99	10.96	216.26	1.28	.203
Type (Pseudo)	20.99	10.92	214.77	1.92	.056±
(normalized) Syllable length	19.30	3.56	312.77	5.42	<.001***
Condition (Experimental)	–49.43	22.02	33.39	–2.25	.032*
Response (yes)	0.44	11.24	226.46	0.04	.969
Type (Hebrew) × Response (yes)	23.89	15.81	227.87	1.51	.132
Type (Pseudo) × Response (yes)	76.22	16.03	237.32	4.76	<.001***
Random effects	Variance (*SD*)				
	Intercept			Slope	
Participant	3,789 (61.56)			–	
Item	1,596 (39.95)			–	
Residual	32,903 (181.39)			–	

Selected Model: buildmer(RT~(1|Subject) + (1|Item) + Type + SyllableLength + Condition + Response + Type: Condition, data = BISRHRT, ddf = "Satterthwaite," REML = FALSE, control = lmerControl(optimizer = "bobyqa"), calc. anova = TRUE, calc.summary = TRUE).
± p <0.1; * $p < .05$; *** $p < 0.001$.

Table 14. Pairwise comparisons with Bonferroni corrections for multiple comparisons on the RT data.

Pairwise comparison	Fixed level	Value	*df*	χ^2	*p*-value
No–yes	English	−0.44	1	0.002	1.00
No–yes	Hebrew	−24.34	1	4.78	.09±
No–yes	Pseudo	−76.66	1	44.90	<.001***
English–Hebrew	No	−13.99	1	1.63	1.00
English–Pseudo	No	−20.99	1	3.70	.33
Hebrew–Pseudo	No	−7.00	1	0.41	1.00
English–Hebrew	Yes	−37.88	1	11.04	.005**
English–Pseudo	Yes	−97.20	1	68.57	<.001***
Hebrew–Pseudo	Yes	−59.32	1	26.33	<.001***

± p <0.1; *** $p < 0.001$.

Table 15. Summary table for the selected model predicting error rate comparing experimental and control among English-Hebrew bilinguals.

Error Rates				
Fixed Effects	Estimate	*SE*	*z*-value	*p*-value
(Intercept)	−9.15	0.77	−11.95	<.001***
Response (Yes)	3.70	0.72	5.14	<.001***

(Continued)

Table 15. (Continued)

z-frequency	−1.06	0.63	−1.68	.092±
Type (Hebrew)	1.59	0.63	2.53	.011*
Type (Pseudo)	1.44	0.84	1.72	.086±

Random effects	Variance (*SD*)	
	Intercept	Slope
Participant	1.13 (1.07)	7.58 (2.75)
Item	8.61 (2.93)	

Selected Model: buildmer (Error~(1 + Response|Subject) + (1|ItemID) + Response + zFreq + Type, data = BISRH2, family = binomial, df = "Wald," REML = FALSE, control = glmerControl(optimizer = "bobyqa"), calc.anova = TRUE, calc.summary = TRUE).
± p <0.1; * $p < .05$; *** $p < 0.001$.

Table 16. Pairwise comparisons with Bonferroni corrections for multiple comparisons on the error rate data.

Pairwise comparison	Value	*df*	χ^2	*p*-value
English–Hebrew	0.17	1	6.43	.034*
English–Pseudo	0.19	1	2.96	.26
Hebrew–Pseudo	0.54	1	0.05	1.00

*A significant difference between the language background groups at the $p < .05$ level.