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Word reading by sequential trilingual: the relative strength of lexical and sub-lexical processing in Arabic and English orthographies

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Abstract
This study investigated the strength of lexical and non-lexical processing among Arabic (L1) English (L3)-speaking children (fourth and fifth grades, N = 532) in two writing systems that vary in terms of transparency. Children were assessed using word reading, phonological and vocabulary measures. In Arabic, the study focused on standard form. Assessing the contribution of phonological and lexical routes to reading accuracy involved the use of structural equation modeling (SEM) analysis. The findings revealed that the contribution of the lexical route was similar in vowelized and unvowelized Arabic orthographies, with an advantage for the latter. Findings indicated that only the phonological route contributed to Arabic pseudoword reading, whereas the lexical route did not. In Arabic word reading, the lexical route's contribution was lower alongside more phonological involvement. However, the phonological route's contribution was lower in deep English orthography alonside higher lexical contribution. The findings support the connectionist model and the varies contribution of the latent variables (lexical and phonological) to reading real Arabic words and English words. They corroborate the view that based on the assumption that this difference in orthographic depth exists, lexical-phonological route involvement varies from one language to another which contributed differently to reading in the two languages. However, they support the traditional dual route model in reading Arabic pseudo word, while separate independent phonological contribution was observed. The findings demonstrate the need for the reconsideration of vowelization as the sole criterion in determining the orthographic transparency/depth continuum of Arabic.

Keywords Reading · Orthographic depth · Arabic · English · Trilingual

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Introduction

Reading is an essential skill that relies on visual, orthographic, phonological, and semantic information (Perfetti, 2007). It involves two basic information processing activities; the first is decoding, where children learn to read based on the Grapho-Phonemic Correspondence (GPC) by translating written letters (graphemes) to the corresponding sound (phonemes). However, to more advanced reading skills, children need to move from this initial and primitive stage to an efficient and fluent one. To do so they need to read bigger orthographic units such as syllables and words, which contribute to more efficient word recognition (Gough & Tunmer, 1986). Based on the dual route view (Coltheart et al., 1993), this latter stage relies more on lexical knowledge that includes the expressive and receptive vocabulary, which are used to reflect processing related to the lexical route. In this case, the lexical route makes activation forward to both whole-word orthographic representations and higher-level semantic information (vocabulary). Therefore, readers identify the different letters of the word (knowledge of the alphabet and orthographic lexicon), this orthographic information makes direct contact with semantic and spoken vocabulary (connections between the printed word and the decoded meaning) (Gough & Tunmer, 1986). The first stage however, relies mainly on phonological awareness (Perry et al., 2019), and thus reflect the non-lexical (phonological) route.

The involvement of both lexical and non-lexical routes in reading may differ between languages depending on the orthographic transparency of the language, which is defined as the correspondence between a word's orthographic (written) units and their phonologic (sounds) forms (Frost, 1998; Seymour et al., 2003). While the phonological route plays a critical role in more transparent orthographies, the involvement of the lexical route seems to be highlighted in more deep orthographies where the GPC is not applicable. Yet, the contribution and availability of the phonological and lexical information may differ between first and second languages due to orthographic-specific influences (specific writing system type of each language: transparent vs. deep orthography) and word exposure and use of oral language in each language (Lallier et al., 2014) and in particular languages that use dialects in their spoken form that are relatively different between the standard and written language, which might be particularly relevant to the diglossic situation in Arabic. Very few studies have shown that exposure to two or more languages concurrently and, as a result, having varying amount of input in each language does not impede phonological development, thereby improving phonological production, when the amount of input, the phonological saliency of the target system, and the degree of relatedness of language systems are all taken into account (Montanari, 2011; Yang & Hua, 2010). Thus, in this study we will test the relevant contribution of lexical and non-lexical routes to reading in transparent and deep orthographies of Arabic and English.

Overall, reading is a cognitive, interactive and important process, in which readers extract meaning and knowledge (Bojovic, 2010). The development of reading may differ between languages because of their orthographic depth. For example, Share (2008) emphasized that characteristics of orthographic depth have always been centered on English; yet, English may be an irregular orthography and orthographic uniqueness affects reading models. In different language scripts, the transparency

of orthographic depth vary (e.g., Aro, 2004; Caravolas et al., 2013; Protopapas & Vlahou, 2009; Ziegler et al., 2010). In languages that have a transparent orthography, such as Indonesian, Italian, and Finnish, surface phonology is reflected in the consistent pronunciation of a given letter in different words (Winskel & Lee, 2014; Ziegler et al., 2010). However, in deep orthographies, such as English, grapheme-phoneme relationships can be ambiguous with a high degree of inconsistent and irregular spellings (Share, 2008; Seymour et al., 2003). A given letter is often pronounced inconstantly in different words, such as the 'a' in *saw* and *cake*. Some letters have no corresponding sound (e.g., 'w' in *answer*), whereas the same sound can have various spellings (e.g., /k/ in *cat, king, opaque*, and *track*).

In the case of orthographic depth, the literature has addressed two approaches to theorizing basic reading components. The first is the traditional dual-route approach of reading, which distinguishes between two independent lexical-orthographic and non-lexical phonological processes for the conversion of letters to sounds (Coltheart et al., 1993, 2001; Zorzi, 2010). The lexical route, which is also called the direct route, involves direct contact between sublexical orthographic information and whole-word orthographic representations. This gives access to both whole-word phonology and higher-level semantic information. This may be applicable to reading languages with deeper orthographies, where the word reading process requires a visual graphic route in order to achieve meaningful comprehension (Forster et al., 1987; Hoosain, 1991). On the non-lexical route, which is also called the indirect route, sublexical orthographic information is transformed into a sublexical phonological code before making contact with phonological output units, whole-word phonological representations, and semantics. Therefore, according to the traditional dual-route model, if the language writing system accurately represents the sounds of the language, i.e. has high orthographic transparency, readers are more likely to rely on non-lexical phonological coding (Forster et al., 1987). In the second approach, which emerged from the modern research of connectionists that has increasingly advocated for more flexible interactions between the two routes, phonological and orthographic processes are more dependent and interconnected (Plaut, 2005; Plaut et al., 1996; Seidenberg & McClelland, 1989; Van Orden et al., 1990). This latter theory claims that there is a single, rather than dual, mechanism for processing words, as well as distributed representations and weighted connections between units, rather than symbolic rules for mapping letters and sounds, although the contributions of different parts may differ. To sum, the dual-route theory would suggest only phonological decoding for transparent orthographies, while connectionist models might show differences, it means that in transparent orthography, phonological and lexical processing are both involved, with stronger phonological processing.

In the case of reading acquisition in languages that vary in their orthographic depth, reading research suggests that reading acquisition is easier in certain orthographies (e.g., Aro & Wimmer, 2003; Seymour et al., 2003). The variation in the orthographic depth of different scripts was found to impact reading acquisition in different languages. The orthographic depth hypothesis (ODH; Katz & Frost, 1992) and the grain size theory (Ziegler & Goswami, 2005), as well as other studies (e.g., Aro & Wimmer, 2003; Caravolas et al., 2013; Seymour et al., 2003) have proposed that transparent or shallow orthographies are easier to read than deep orthographies with

highly inconsistent grapheme-phoneme coding. For example, Seymour et al. (2003) examined the differences in the rates of acquisition of literacy components in European languages that vary in their orthographic depth. They tested letter knowledge, familiar word reading, and simple nonword reading in English and 12 other European orthographies (Finnish, Greek, Italian, Spanish, German, Norwegian, Icelandic, Portuguese, Dutch, Swedish, French, and Danish). The findings revealed that Scottish English-speaking children (aged 5 to 7 years) performed poorly in accuracy tests by the end of the first school year, and read only 29% of English pseudowords correctly. Aro & Wimmer (2003) examined numeral reading in English, number-word reading, and pseudoword reading among English-speaking children and compared them to German-, Dutch-, Finnish-, French-, Spanish-, and Swedish-speaking children in grades 1 to 4. By the end of the first year, the Dutch-, German-, Finnish-, and Spanish-speaking children demonstrated 85% reading accuracy for pseudowords, whereas the Swedish-speaking children demonstrated 90% reading accuracy. However, the English-speaking children demonstrated only 50% accuracy. They did not close the gap in accuracy levels when compared to their peers until grade 4. This shows that the ability to translate graphemes into acceptable pronunciations was easily demonstrated in all the orthographies tested, except English.

Overall, similar to monolinguals, research has indicated the existence of orthographic-specific influences on reading in bilinguals in two orthographies simultaneously. Lallier et al. (2014) examined reading words among Spanish-French balanced bilingual children (aged 9 to 12 years) in both their deep (French) and shallow (Spanish) orthographies. The findings indicated that bilingual children were more accurate at reading in their shallow orthographies than in their deep ones. This shows that orthographic depth impacts lexicality effects, indicating that bilinguals rely more on the lexical process when they read in their deep than in their shallow or transparent orthographies. In the context of relations between first and second languages in reading acquisition among bilinguals, it was found that L1 has a positive impact on L2 reading skills (Jiang & Kuehn, 2001; Perfetti et al., 2002). Based on the interdependence hypothesis of Cummins (1979), which suggests that Cognitive Academic Language Proficiency (CALP) is transferred between languages, researchers have proposed that good linguistic skill in L1 predicts similar skill in the second language (Leikin et al., 2005). Therefore, bilingual students can transfer reading skills, such as phonological skills and word identification skills between their languages (Abu-Rabia et al., 2012).

The impact of orthographic depth on reading was also found in the predictors of reading accuracy between orthographies. for example, Ziegler et al. (2010), investigated the role of phonological awareness, memory, vocabulary, rapid naming, and nonverbal intelligence on reading performance across five different languages that varied in their orthographic transparency (Finnish, Hungarian, Dutch, Portuguese, and French). The sample included 1,265 children from the second grade. The findings revealed that phonological awareness was the main predictor of reading fluency in all five languages, but its impact was modulated by the transparency of the orthography, being stronger in less transparent orthographies. Also, the importance of phonological awareness, as one of the predictors of reading performance, was relatively universal across the alphabetic languages studied, though its precise weight varied systemati-

cally as a function of script transparency. The influences of phonological awareness and vocabulary were modulated such that phonological awareness was a more important component in opaque orthographies compare to vocabulary which was a more important component in transparent orthographies. As a result, a reader will read familiar words using more the lexical-orthographic processing alongside non-lexical processing, whereas new and unfamiliar lexical items will prompt them to use more non-lexical routes involving grapheme-phoneme coding alongside lexical processing (Seidenberg, 1985). This is particularly relevant in the context of diglossic reality in Arabic, which also has its unique orthographic system.

Arabic: orthography and diglossia

Reading acquisition in Arabic is a challenging process for children (Eviatar et al., 2004). It is affected by a number of factors. The first is the complexity of Arabic orthography (Eviatar & Ibrahim, 2014), which slows reading acquisition (Saiegh-Haddad, 2003). The Arabic alphabet consists of 28 letters representing consonants. All letters are written from right to left. In some cases, the letters are connected together from both sides, in other cases they are not connected. It also includes three vowel signs (short and long) (Abu Chacra, 2017). The vowelized written words represent the shallow or transparent orthography that is presented to beginner readers. Around the third grade, a non-vowelized written system is presented to them in various written texts and materials. So, unlike Roman orthographies, where each language has a transparent or deep writing system, based on how orthography represents phonology, Arabic orthographic systems have shallow and deep representations (Katz & Frost, 1992). The unvowelized writing system in Arabic challenges readers with its high number of homographs. Thus, it requires relying on general contextual clues in order to identify the correct pronunciation and meaning of specific words. For example, (أكل/ʔakel /'food', أَكَلَ/ʔakal/'ate') have similar letters when vowelization diacritics are omitted. Therefore, readers have to rely on general context to infer pronunciation and meaning of those words.

Some researchers have indicated that vowelization contributes to word recognition in Arabic because of the phonological contribution of vowel diacritics while reading (Abu-Rabia, 1998, 1999, 2007). In contrast, Ibrahim (2013) revealed that unvowelized words were read more fluently than full vowelized words among native Arab eighth graders. These results can be explained by the visual load produced by vowelization diacritics while reading familiar words. Asadi (2017) examined the effect of diacritics for short vowels on the accuracy and fluency of reading in Arabic among children from the first to sixth grades using unvowelized and fully vowelized words. The findings showed that children read unvowelized words more fluently and accurately across all grades, except for those in the first and second grades, who showed equal reading accuracies.

Notably, the involvement of lexical and non-lexical components in predicting reading was examined in orthographic depth context in the Arabic language. Asadi and Khateb (2017) examined the involvement of lexical (vocabulary) and non-lexical (phonological awareness) components in predicting reading based on orthographic

transparency of Arabic among first and second readers. Findings revealed that the prediction of phonological awareness to reading was strong and similar both in the vowelized/transparent and unvowelized/deep orthographies and decreased in the second grade in both versions. The contribution of vocabulary to reading was slightly higher in the unvowelized orthography compared to the vowelized version, and it increased with age. It seems that at the beginning of reading, the lexical route is not available to children and as they learn the alphabet they move on to processing words as a whole. Thus, when it comes to reading in Arabic, the relative strength of lexical and non-lexical processing seems to be a narrow framework.

As a result, the contribution and availability of phonological and lexical information may differ between languages, particularly in diglossic languages such as Arabic, where the spoken form differs significantly from the standard written form. In Arabic, diglossia refers to the existence of two forms of the same language: spoken Arabic (SA), which is acquired at home from birth and is dominantly used prior to schooling, and modern standard Arabic (MSA), which is formally learned and used around the age of 5–6 when children begin formal schooling (Ferguson, 1959; Omar, 1973), implying that MSA is not the first language of children who speak Arabic. Given the large linguistic distance between MSA and SA, diglossia has had a negative impact on Arabic reading acquisition and literacy development (Abu Ahmad et al., 2014; Saiegh-Haddad, 2007; Saiegh-Haddad et al., 2011). According to Abu-Rabia (2000), diglossia is a significant factor influencing low levels of reading among Arab speakers. Similarly, Saiegh-Haddad and Schiff (2016) discovered differences in reading MSA versus SA words in elementary school, supporting the effect of linguistic distance on the development of word reading in Arabic. However, it appears that lexical and non-lexical processing in Arabic are speculative and need to be empirically tested due to its diglossic nature (along with orthographic depth and complexity), which may result in low efficiency in automatic lexical processing, since children are not exposed sufficiently to unfamiliar MSA words, which may lead to involving stronger non-lexical processing while reading. When compared to other languages (such as English), which have unified spoken and written forms, phonological representations in Arabic written form differ from those in spoken form.

The present study

Studying reading among children in both transparent and deep orthographies simultaneously is a powerful approach that can provide useful insights on reading development in different orthographies and languages, by examining whether the reading system in two orthographies (languages) is flexible to the orthography that represented. Apart from the grain size accommodation hypothesis that postulates that bilinguals have similar reading mechanisms that are influenced by their reading experience in both their languages, few studies suggest that they adapt depending on the depth of the language **(**Egan we al., 2019). Accordingly, few studies in language reading research have investigated the lexical and non-lexical processes in bilingual (or trilingual) contexts in general, or among native Arabic speakers in particular. If the balance between lexical and non-lexical processing is language-specific (Frost et

al., 1987; Katz & Feldman, 1983; Katz & Frost, 1992), this assumption would have important consequences for understanding reading in different languages.

Given the co-occurrence of diglossia and orthographic transparency in Arabic, especially Arabic uniqueness, and the difference between predictors of reading acquisition in Arabic vs. English, based on the assumption that there is diffrence in the orthographic depth of Arabic (its two versions: vowelized/transparent and unvowelized/deep) vs. English, the current study compares the involvement of lexical vs. phonological routes to reading in these languages. It will be informative to compare the involvement of lexical vs. phonological routes to reading between vowelized and unvowelized Arabic (L1) and English (L3). The logical hypotheses in this case is that in the deeper English orthography as well as unvowelized Arabic script, variables related to lexical reading would be more clearly linked to reading skills, while variables linked to phonological decoding would be related to reading vowelized Arabic.

Taking into account the different orthographic depths of Arabic (and its unique features) and English, examining word reading in Arabic can determine whether the traditional dual-route model or connectionist model are applicable to it. Thus, it is interesting to see whether young Arabic sequential trilinguals have functionally separate lexicons for each form of their languages (L1 and L3). Accordingly, our research question is as follows: Are there differences between the relative contributions of lexical and non-lexical processing in word reading according to the the existed assumption of orthographic depth in transparent vs. deep orthographies in Arabic (L1, vowelized and unvowelized) and deep English (L3)?

Methods

Participants

A total of 532 trilingual Israeli Arabic-speaking children (289 girls) participated in this study. The sample comprised 267 and 265 participants from the fourth ($M_{\text{age in month}}$ = 117.2; SD=6.1) and fifth ($M_{\text{age in month}}$ = 129.3; SD=5.8) grades, respectively. They were recruited from 33 Arabic-speaking elementary schools from the north, center, and south of Israel, and came from various socioeconomic backgrounds. The children were native speakers of different dialects from the north, and the Triangle region in Israel. The group consisted of sequential trilingual children who spoke Arabic as their native language; it was the main instructional language in their schools, while they studied Hebrew (second language starting from second grade) and English (as a third language from third grade) as additional required subjects. Because English was learned beginning in third grade, the best opportunity to examine reading acquisition of Arabic and English was from fourth and fifth grade.

The teachers in the target programs used the specified curriculum provided by the Israeli Ministry of Education. Children had studied Hebrew (L2) for two hours a week from second grade (and five hours a week from third grade), and English (L3) for five hours a week from third grade. When children start learning to read vowelized Arabic, the teaching instructions focus on graphemic-phonemic recoding and decod-

ing strategies. Children start learning to read in English in the beginning of grade three. The inconsistent orthography forces them to rely on larger orthographic units more than on phonemes and grapho-phonemic recoding strategies alone. Decoding is also taught when learning to read in English, however, the focus is on whole-word reading.

The tester selected every fourth name from the class list (approximately eight children per class). The study was approved by the college ethical committee. Only children who presented filled parental consent forms participated in the study. All participants were in regular classes – that is, none of them were in special education classes. None of them had visual, hearing, language, or learning difficulties of any kind.

Measures

Children were assessed using measures of isolated word reading in Arabic and English, phonological awareness and memory, and vocabulary. The measures used here were presented to five teachers who worked with children in this age group, and all of them thought that the items were appropriate for students of the fourth and fifth grade. All measures, except for word reading in English, were used in previous studies (Asadi & Khateb, 2017; Asadi, 2020).

Arabic word reading

This test examined the reading accuracy of Arabic vowelized words. The task comprised 30 vowelized words from children's third- and fourth-grade textbooks. The words represented several morphological patterns in Arabic and varied in terms of length (two to four syllables) and the children's familiarity (low, medium, and high). An identical list of non-vowelized (without short vowels), but not homographic words was also presented. Non-homographic words were chosen to avoid the probability of the words being read correctly while being pronounced differently. A third list of pseudowords comprising the same words as those of the vowelized version (after changing two phonemes such that the words became meaningless in Arabic) was also included. Each participant was required to read the words out loud as accurately as possible at a rate that suited them. The participants' scores were based on the total number of correctly read items, with a maximum score of 30 in each version. The reliability (Cronbach's α) was 0.93, 0.88, and 0.91 for the vowelized, non-vowelized, and pseudowords versions, respectively.

English word reading

This test examined the reading accuracy of the isolated words in English. The task comprised 30 words from children's third- and fourth-grade textbooks. Most of the words were monosyllabic, whereas a few were bi-syllabic and disyllabic. The words varied in terms of children's familiarity (low, medium, and high). To assess words familiarity, five English teachers were required to point to a list of stimuli to indicate

children degree of familiarity to words (to what degree the word is familiar to children) (Noble, 1952).

Like the Arabic reading task, each participant was required to read the words out loud as accurately as possible at a rate that suited them. The participants' scores were based on the total number of correctly read items, with a maximum score of 30. The reliability of the test (Cronbach's α) was 0.92.

Phonemic deletion (in Arabic)

This test examined the ability to delete phonemes at the beginning (40) and at the end (40) of words. The items were mono- and disyllabic and included three to six phonemes. They were generated from the SA (20 items), MSA (20 items), shared[1] (20 items) and pseudo words (20 items). During the test, each word was read out to the participant, who had to repeat it after the examiner and then say it again after deleting a specific phoneme. One point was assigned for every successfully deleted final or initial phoneme, with a maximum score of 80. The reliability of the test (α) was 0.92.

Phonemic segmentation (in Arabic)

This test examined the ability to repeat and segment words into their basic sounds. The items used in this task were the same as those used in the phonemic deletion task. The participant had to repeat each word after the examiner and segment it into separate sounds. One point was assigned to every successfully segmented word with a maximum score of 80. The reliability of the test (α) was 0.90.

Receptive vocabulary (in Arabic)

This test evaluated semantic knowledge at the perceptual level using a list of 30 literary Arabic words including verbs, nouns, and adjectives. The participant heard a target word followed by three other words and was required to choose the one word that had a similar meaning (synonym) to that of the target word. Each correct answer earned one point. The maximum score was 30. The reliability of the test (α) was 0.82.

Expressive vocabulary (in Arabic)

This test examined semantic knowledge at the production level using a list of 32 literary Arabic words including verbs, expressions of time, quantity, and adjectives. Each word was presented auditorily to the participant, who was asked to give its opposite. Each answer was compared to the possible list of correct answers. Each correct answer earned one point. The maximum score was 32. The reliability of the test (α) was 0.83.

[1] Shared items refer to words that are similar across SA and MSA.

Table 1 Descriptive statistics of raw scores mean and SD

Variables				
	M	*SD*	*Min*	*Max*
Word reading				
Arabic pseudo-words	18.6	7.4	0	30
Arabic vowelized/shallow	24.3	6.4	3	30
Arabic unvowelized/deep	26.1	3.6	9	30
English	21.1	6.9	0	30
Phonological route				
Phonemic segmentation	57.3	13.9	9	80
Phonemic deletion	66.9	9.4	26	80
Lexical route				
Receptive vocabulary	22.4	4.5	10	30
Expressive vocabulary	26.1	4.3	12	32

Procedure

The participants were tested individually by the examiner in a quiet room in two short testing sessions in the third trimester (between April and June). To prevent the effects of fatigue and to avoid fluctuations in concentration among the participants, there were short breaks after each test. In one session, the children took the Arabic word reading test and one test on phonological awareness and vocabulary. In the other session, which took place about one or two weeks later, the children took the English word reading test and phonological awareness and vocabulary. All examiners were students in the field of education and had received specific and detailed training on administering the different tasks.

Results

Table 1 presents the descriptive statistics of the observed variables of the participants' scores. The means reflect the raw scores of all variables. The performance was acceptable for all variables. There were no indications of floor or ceiling effects. Bivariate correlation.

among all the observed variables are presented in Table 2. As shown in Table 2, there were significant correlations between all variables ranging from 0.26 to 0.64 ($p < .001$). Arabic Pseudo word reding correlated positively with Arabic-vowelized/transparent (r = .64, $p < .001$), and Arabic-unvowelized/deep (r = .47, $p < .001$). English word reading also correlated positively with phonemic segmentation (r = .40, $p < .001$), phonemic deletion (r = .42, $p < .001$), receptive vocabulary (r = .45, $p < .001$), and expressive vocabulary (r = .43, $p < .001$).

Structural equation modeling (SEM) analysis was used to assess the relative contribution of the basic components of the phonological and lexical routes to reading accuracy. Maximum likelihood estimation procedures were used to analyze the explained variance of the predictors (latent variables) using AMOS 20.0 (Arbuckle, 2011), simultaneously in reading Arabic (pseudowords, vowelized/transparent and unvowelized/deep versions) and in English. The goodness of fit indices used were the

Table 2 Correlation analyses* for all observed variables

Variables	1	2	3	4	5	6	7	8
1. Arabic pseudo-words	-							
2. Arabic-vowelized/transparent	64.	-						
3. Arabic-unvowelized/deep	47.	51.	-					
4. English	42.	45.	48.	-				
5. Phonemic segmentation	40.	40.	37.	40.	-			
6. Phonemic deletion	40.	44.	44.	42.	62.	-		
7. Receptive vocabulary	26.	36.	36.	45.	38.	39.	-	
8. Expressive vocabulary	26.	33.	37.	43.	43.	39.	53.	-

*n: All correlation-values were significant at $p < .001$

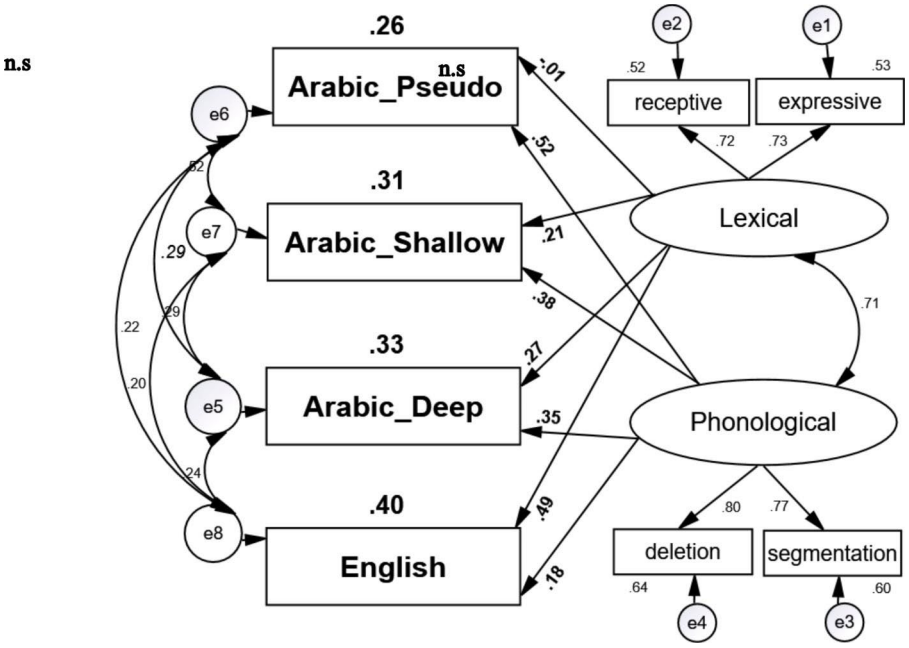

Fig. 1 Structural equation model for predicting word reading accuracy in Arabic (pseudo-words, vowelized/transparent and unvowelized/deep orthographies) and in English languages. Note: All contributions (Beta-β) of the latent variables were significant at p < .001, otherwise specified. n.s = non-significant; *p < .05

root mean square error of approximation (RMSEA), the comparative fit index (CFI), and the Tucker-Lewis Index (TLI). As indicated by the fit indices, RMSEA = 0.02, CFI = 0.99, and TLI = 0.99, the SEM model had a good fit to the data.

The results of the SEM analysis showed that the latent variables of both the phonological (represented by phonological deletion and phonemic segmentation) and lexical (represented by receptive and expressive vocabulary) routes explained 26% of the variance in pseudowords, 31% in vowelized/transparent Arabic, 33% in the unvowelized/deep Arabic orthographies, and 40% in English (see Fig. 1). The contributions of both latent independent variables to reading were significant in all versions,

except for that of the lexical component to pseudowords, which was not significant. In Arabic real word reading, the contribution of the latent variables was similar in the vowelized/transparent and unvowelized/deep versions, with a higher contribution of the lexical route in the unvowelized/deep version. Compared with English, the contribution of the independent latent variables, shown by the standardized coefficients (*Beta-β*), provided opposite patterns between the vowelized/transparent Arabic and the deep English models. Whereas the contribution of the lexical component was more dominant in English ($\beta = 0.49$; $p < .001$) than in vowelized/transparent Arabic ($\beta = 0.21$; $p < .05$), the phonological contribution was more dominant in vowelized/transparent Arabic ($\beta = 0.38$; $p < .001$) than in English ($\beta = 0.20$; $p < .05$). This pattern was also present, but more moderately, when comparing English with unvowelized/deep Arabic.

Discussion

This study examined the differences between the relative contributions of lexical and non-lexical processing among Arabic-speaking children in Arabic (L1) and English (L3) word reading. The results showed that the contribution of the latent independent variables (lexical and phonological) to reading gradually changed based on the orthographic depth. They also seemed to be dependent components.

The contribution of the lexical route was minimal in Arabic pseudowords, increased in Arabic vowelized and unvowelized words, and increased significantly in English word reading. However, the contribution of the phonological variable was maximal in Arabic pseudowords, and decreased in Arabic vowelized and unvowelized words, until it decreased significantly in English word reading. This finding supports the approach in which lexical-phonological route involvement is thought to vary from one language to another, depending on the orthographic depth of the language (Share, 2008). As for Arabic real word reading, the contribution of the latent variables was similar in the vowelized/transparent and unvowelized deep versions, with a higher contribution of the lexical route in the latter. While the contribution of the lexical component was more dominant in English than in vowelized/transparent Arabic, the phonological contribution was more dominant in vowelized/transparent Arabic. This pattern was also present, but more moderately, while comparing English with unvowelized/deep Arabic.

These findings align with those of earlier studies on monolinguals and bilinguals (Forster et al., 1987; Goswami et al., 2001; Hoosain, 1991), indicating that the different involvement of lexical or non-lexical routes is based on the orthographic depth of different languages. Readers of Arabic, a more transparent orthography compared to English, were more likely to rely on non-lexical phonological coding. However, a direct lexical process was more applicable to reading in deeper orthography (English). Based on the dual-route model, the phonological route alone contributed to Arabic pseudoword reading. The contribution of the lexical route was almost non-existent. As expected, according to the dual-route model, pseudowords in Arabic represent the sounds of the language with high orthographic transparency. As readers were not exposed to non-words (they had no supporting visual information), they were more

inclined to rely on non-lexical phonological coding (Goswami et al., 2001; Hoosain, 1991). This finding imply that at the beginning of reading (when the vowelized script is introduced first), the lexical route is not available to children and as they learn the alphabet they move on to whole-word orthographic representations and processing.

Despite the fact that this difference is minor, the conclusion that raises the orthographic depth question in Arabic is ambiguous, implying that we cannot assess Arabic orthographic transparency solely on vowelization. This contradicts the Arabic transparency assumption for vowelized words. Asadi and Khateb (2017) conducted a previous large-scale cross-sectional study on vowelized Arabic reading among first to sixth graders. The findings showed that vowelized Arabic differed from other transparent orthographies, with consistent contributions of phonological awareness to reading transparent orthographies through sixth grade. These findings are consistent with previous research on the long-term impact of phonological awareness on Arabic reading (Abu-Rabia et al., 2003; Mannai & Everatt, 2005; Taibah & Haynes, 2011). Moreover, the Asadi and Khateb (2017) investigated the role of phonological awareness and vocabulary in first- and second-grade Arabic children reading vowelized/transparent and unvowelized/deep orthographies. The results revealed that the contribution of phonological awareness to reading was strong and similar in both the vowelized/transparent and unvowelized/deep orthographies, and decreased in both versions in the second grade. The contribution of vocabulary to reading, on the other hand, increased with grade and was greater in the unvowelized orthography. As a result, the minimal difference between vowelized/transparent and unvowelized/deep orthographies can be attributed to Arabic's vowelization feature, which requires a reader to decode all available phonological information (Asadi & Khateb, 2017). However, the similar involvement of phonological and lexical routes in reading in both vowelized and unvowelized versions (observed in this study) may imply that vowelization, the solely criterion for transparency/depth in Arabic, does not improve reading performance as previously suggested (Saiegh-Haddad & Schiff, 2016; Taha, 2016).

The difference in contribution of the lexical route was minimal in both vowelized and unvowelized orthographies, with a slight advantage for the latter. Children in the fourth and fifth grades seemed rather dependent on the phonological route, and had not developed word patterns efficiently. This insufficient lexical contribution to reading both vowelized and unvowelized orthographies in Arabic may be related to diglossia, which may lead to less efficient automatic lexical processes and has a negative effect on reading acquisition (Abu Ahmad et al., 2014; Saiegh-Haddad, 2007; Saiegh-Haddad et al., 2011). These results have implications for lexical processes in reading in Arabic, where words must be retrieved from a complex words in the lexicon including both MSA and SA words (Nevat et al., 2014). Some linguistic skills in standard Arabic are not well promoted in children's oral language. This can negatively affect the relationship between these standard linguistic skills in the oral language and their correspondents in the written language. The lexical quality hypothesis (Perfetti, 2007) posits that different features and characteristics of words (including phonological, morphological, semantic, and syntactic characteristics), represent the properties of the mental lexicon. The quality of these representations is thought to be influenced by the experiences of children in using their oral language.

Researchers have claimed that Arabic-speaking children arrive at school with some immaturity in different aspects of their literary oral language that are less represented in their mental lexicon (Saiegh-Haddad & Joshi, 2014) and are considered, along with the complexity of the orthographic system (Ibrahim et al., 2002), one of the main reasons for the difficulties that Arabic-speaking children face in their reading acquisition (Saiegh-Haddad, 2003).

To conclude, lexical vs. phonological route involvement varies between languages, based on their depth. The shallow/deep orthography in the same language, Arabic, didn't yield differences, thus, there is a need for reconsideration of vowelization as the sole criterion in determining the orthographic transparency/depth continuum of Arabic. Based on the dual-route model, only the phonological route contributed to Arabic pseudoword reading, whereas the lexical route did not. However, varied contibution of lexical and phonological routes was observed in English and Arabic word reading, English requires more lexical skills alongside phonological ones, while Arabic requires more phonological skills alongside lexical ones. The findings of this study have important theoretical implications. They support the connectionist model and the varies contribution of the latent variables (lexical and phonological) to reading Arabic real words and English words. They corroborate the view that based on the assumption that this difference in orthographic depth exists, lexical-phonological route involvement varies from one language to another which contributed differently to reading in the two languages as was argued by the connectionist model, rather than traditional dual route model which indicated that the two routes are independent. However, they support the traditional dual route model in reading Arabic pseudoword, while separate independent phonological contribution was observed. Thus, our findings may impact the validity and suitability of the dual route model to Arabic (Share, 2008) since the contribution of lexical vs. phonological routes to reading did not differ according to writing system (vowelized/transparent vs. non-vowelized/deep) while reading real words. Thus, we have to postulate the dual route model carefully in case of Arabic because its orthographic depth did not differ on the two different writing systems (vowelized and non-vowelized), this calls into question the issue of transparency in Arabic.

Unlike previous work that has highlighted how Arabic and English is read, mostly separately, the current study demonstrates Arabic and English reading processes simultaneously, showing that the same reader may involve different lexical and phonological processing based on the orthographic depth of the language, necessitating different instructional approach for each of them.

The current research implies that the focus of Arabic language approach among Arabic speaking children is different from English. From first grade, children become used to analytic-based reading instruction when reading Arabic (and later reading Hebrew as a similar Semitic language); however, this approach may not be applicable to English reading, which requires high lexical alongside phonological skills in the instruction as reflected in our findings. Therefore, the current study recommends English teachers to focus on lexical and whole language reading in their instruction alongside phonological decoding, which is different from the analytic-based reading used in Arabic and Hebrew. The current study encourages policymakers to bring the research and applied field together to help Arabic speaking children to overcome

obstacles in reading English in particular, and other readers who may encounter similar situations in reading and learning different and distant orthographies. It calls for language teachers to implement adequate strategies and instruction to help Arabic pupils become fluent readers in English, and proposes English instruction or exposure to especially lexical English words (alongside phonological decoding) begin at an earlier age before access to written English. Moreover, this study demonstrates the contribution of Arabic phonological and lexical skills to reading in English, it shows the contribution of L1 skills to L3 reading. The results recommend policymakers to not reconsidering vowelization as the sole criterion for determining orthographic transparency/depth continuum in Arabic.

This study also highlights the centrality of enriching children in MSA word patterns to minimize the gap between written and spoken language and to develop a lexical route for words. Future research should test reading speed rather than accuracy. It should include sentences and texts rather than isolated words to better understand how the two orthographic versions of Arabic are read when compared to English. Moreover, it should examine the relative strength of lexical and non-lexical processing in Arabic, Hebrew (two similar Semitic languages) and English orthographies. It should be noted that English among our population is L3, which may impact and impede their knowledge of English, future studies should examine our research question when English is L2 among Arabic speakers. Researchers should also examine this question among sixth or seventh grade students, when they are more proficient in English, and consider controlling for factors such as non-verbal intelligence, and also to test orthographic knowledge.

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References

Abu Ahmad, H., Ibrahim, R., & Share, D. L. (2014). Cognitive predictors of early reading ability in Arabic: A longitudinal study from kindergarten to grade 2. *Literacy Studies* (pp. 171–194). Dordrecht: Springer. https://doi.org/10.1007/978-94-017-8545-7_8

Abu-Chacra, F. (2017). *Arabic: an essential grammar*. Routledge

Abu-Rabia, S. (1998). Effects of text type, reader type and vowelization. Reading Arabic Texts. *Reading and Writing*, *10*(2), 105–119. https://doi.org/10.1023/A:1007906222227

Abu-Rabia, S. (1999). The effect of Arabic vowels on the reading comprehension of second- and sixth-grade native Arab children. *Journal of Psycholinguistic Research*, *28*(1), 93–101. https://doi.org/10.1023/a:1023291620997

Abu-Rabia, S. (2000). Effects of exposure to literary Arabic on reading comprehension in a diglossic situation. *Reading and Writing: an Interdisciplinary Journal*, *13*(1), 147–157

Abu-Rabia, S. (2007). The role of morphology and short vowelization in reading Arabic among normal and dyslexic readers in grades 3, 6, 9, and 12. *Journal of Psycholinguistic Research*, *36*(2), 89–106. https://doi.org/10.1007/s10936-006-9035-6

Abu-Rabia, S., & Bluestein-Danon, D. (2012). A study into the results of an intervention program of linguistic skills in English (L2) and its effect on Hebrew (L1) among poor readers: An examination of the cognitive-retroactive transfer (CRT) hypothesis. *Open Journal of Modern Linguistics*, *2*(04), 131

Abu-Rabia, S., Share, D., & Mansour, M. S. (2003). Word recognition and basic cognitive processes among reading-disabled and normal readers in Arabic. *Reading and Writing*, *16*(5), 423–442. https://doi.org/10.1023/A:1024237415143

al Mannai, H. A., & Everatt, J. (2005). Phonological processing skills as predictors of literacy amongst Arabic speaking Bahraini children. *Dyslexia*, *11*(4), 269–291. https://doi.org/10.1002/dys.303

Arbuckle, J. L. (2011). *IBM SPSS Amos 20 user's guide*. SPSS Inc: Amos Development Corporation

Aro, M. (2004). *Learning to read: The effect of orthography (Jyväskylä studies in education, psychology and social research, Publication No. 237). Jyväskylä*. University of Jyväskylä

Aro, M., & Wimmer, H. (2003). Learning to read: English in comparison to six more regular orthographies. *Applied Psycholinguistics*, *24*(4), 621–635. https://doi.org/10.1017/S0142716403000316

Asadi, I. A. (2020). Predicting reading comprehension in Arabic-speaking middle schoolers using linguistic measures. *Reading Psychology, 41*(2), 87–109. https://doi.org/10.1080/02702711.2020.1726846

Asadi, I. A., & Khateb, A. (2017). Predicting Reading in Vowelized and Unvowelized Arabic Script: An Investigation of Reading in First and Second Grades. *Reading Psychology, 38*(5), 486–505. https://doi.org/10.1080/02702711.2017.1299821

Bojovic, M. (2010). Reading skills and reading comprehension in English for specific purposes. In *The international language conference on the importance of learning professional foreign languages for communication between cultures* (Vol. 23, No. 9, pp. 1–6)

Caravolas, M., Lervåg, A., Defior, S., Seidlová Málková, G., & Hulme, C. (2013). Different patterns, but equivalent predictors, of growth in reading in consistent and inconsistent orthographies. *Psychological Science*, *24*(8), 1398–1407. https://doi.org/10.1177/0956797612473122

Coltheart, M., Curtis, B., Atkins, P., & Haller, M. (1993). Models of reading aloud: Dual-route and parallel-distributed-processing approaches. *Psychological Review*, *100*(4), 589–608. https://doi.org/10.1037/0033-295X.100.4.589

Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J. (2001). DRC: A dual route cascaded model of visual word recognition and reading aloud. *Psychological Review*, *108*(1), 204–256. https://doi.org/10.1037/0033-295x.108.1.204

Cummins, J. (1979). *Cognitive/academic language proficiency, linguistic interdependence, the optimum age question and some other matters. Working papers on bilingualism* Vol. 19

Egan, C., Oppenheim, G. M., Saville, C., Moll, K., & Jones, M. W. (2019). Bilinguals apply language-specific grain sizes during sentence reading. *Cognition*, *193*, 104018

Eviatar, Z., & Ibrahim, R. (2014). Why is it hard to read Arabic?. In E. Saiegh-Haddad, & M. Joshi (Eds.), *Handbook of Arabic literacy: Insights and perspectives* (pp. 77–96). Dordrecht: Springer

Eviatar, Z., Ibrahim, R., & Ganayim, D. (2004). Orthography and the hemispheres: Visual and linguistic aspects of letter processing. *Neuropsychology*, *18*(1), 174–184. https://doi.org/10.1037/0894-4105.18.1.174

Ferguson, C. A. (1959). Diglossia. *WORD*, *15*(2), 325–340. https://doi.org/10.1080/00437956.1959.11659702

Forster, K. I., Davis, C., Schoknecht, C., & Carter, R. (1987). Masked priming with graphemically related forms: Repetition or partial activation? *The Quarterly Journal of Experimental Psychology Section A*, *39*(2), 211–251. https://doi.org/10.1080/14640748708401785

Frost, R. (1998). Toward a strong phonological theory of visual word recognition: True issues and false trails. *Psychological Bulletin*, *123*(1), 71–99. https://doi.org/10.1037/0033-2909.123.1.71

Frost, R., Katz, L., & Bentin, S. (1987). Strategies for visual word recognition and orthographical depth: A multilingual comparison. *Journal of Experimental Psychology Human Perception and Performance*, *13*(1), 104–115. https://doi.org/10.1037//0096-1523.13.1.104

Goswami, U., Ziegler, J. C., Dalton, L., & Schneider, W. (2001). Pseudohomophone effects and phonological recoding procedures in reading development in English and German. *Journal of Memory and Language*, *45*(4), 648–664. https://doi.org/10.1006/jmla.2001.2790

Gough, P. B., & Tunmer, W. E. (1986). Decoding, reading, and reading disability. *Remedial and Special Education*, *7*(1), 6–10. https://doi.org/10.1177/074193258600700104

Hoosain, R. (1991). *Psycholinguistic implications for linguistic relativity: A case study of Chinese*. Hillsdale, NJ: Lawrence Erlbaum

Ibrahim, R. (2013). Reading in Arabic: New evidence for the role of vowel signs. *Creative Education*, *04*(4), 248–253. https://doi.org/10.4236/ce.2013.44036

Ibrahim, R., Eviatar, Z., & Aharon-Peretz, J. (2002). The characteristics of Arabic orthography slow its processing. *Neuropsychology*, *16*(3), 322–326. https://doi.org/10.1037//0894-4105.16.3.322

Jiang, B., & Kuehn, P. (2001). Transfer in the academic language development of post-secondary ESL students. *Bilingual Research Journal*, *25*(4), 653–672

Katz, L., & Feldman, L. B. (1983). Relation between pronunciation and recognition of printed words in deep and shallow orthographies. *Journal of Experimental Psychology Learning Memory and Cognition*, *9*(1), 157–166. https://doi.org/10.1037//0278-7393.9.1.157

Katz, L., & Frost, R. (1992). The reading process is different for different orthographies: The orthographic depth hypothesis. In R. Frost, & L. Katz (Eds.), *Orthography, phonology, morphology, and meaning*, (pp. 67–84). North-Holland

Lallier, M., Valdois, S., Lassus-Sangosse, D., Prado, C., & Kandel, S. (2014). Impact of orthographic transparency on typical and atypical reading development: Evidence in French-Spanish bilingual children. *Research in Developmental Disabilities*, *35*(5), 1177–1190. https://doi.org/10.1016/j.ridd.2014.01.021

Leikin, M., Share, D. L., & Schwartz, M. (2005). Difficulties in L2 Hebrew reading in Russian-speaking second graders. *Reading and Writing*, *18*(5), 455–472. https://doi.org/10.1007/s11145-005-8919-4

Montanari, S. (2011). Phonological differentiation before age two in a Tagalog–Spanish–English trilingual child. *International Journal of Multilingualism*, *8*(1), 5–21. https://doi.org/10.1080/14790711003671846

Nevat, M., Khateb, A., & Prior, A. (2014). When first language is not first: An functional magnetic resonance imaging investigation of the neural basis of diglossia in Arabic. *European Journal of Neuroscience*, *40*(9), 3387–3395. https://doi.org/10.1111/ejn.12673

Noble, C. E. (1953). The meaning-familiarity relationship. *Psychological Review*, *60*(2), 89

Omar, M. K. (1973). *The acquisition of Egyptian Arabic as native language*. The Hague: Mouton

Perfetti, C. (2007). Reading ability: Lexical quality to comprehension. *Scientific Studies of Reading*, *11*(4), 357–383. https://doi.org/10.1080/10888430701530730

Perfetti, C. A., Liu, Y., & Tan, L. H. (2002). *How the mind can meet the brain in reading*. A comparative writing systems approach

Perry, C., Zorzi, M., & Ziegler, J. C. (2019). Understanding dyslexia through personalized large-scale computational models. *Psychological Science*, *30*(3), 386–395. https://doi.org/10.1177/0956797618823540

Plaut, D. C. (2005). Connectionist approaches to reading. In M. J. Snowling, & C. Hulme (Eds.), *The science of reading: A handbook* (pp. 24–38). Blackwell Publishing

Plaut, D. C., McClelland, J. L., Seidenberg, M. S., & Patterson, K. (1996). Understanding normal and impaired word reading: Computational principles in quasi-regular domains. *Psychological Review*, *103*(1), 56–115. https://doi.org/10.1037/0033-295x.103.1.56

Protopapas, A., & Vlahou, E. L. (2009). A comparative quantitative analysis of Greek orthographic transparency. *Behavior Research Methods*, *41*(4), 991–1008. https://doi.org/10.3758/BRM.41.4.991

Saiegh-Haddad, E. (2003). Linguistic distance and initial reading acquisition: The case of Arabic diglossia. *Applied Psycholinguistics*, *24*(3), 431–451. https://doi.org/10.1017/S0142716403000225

Saiegh-Haddad, E. (2007). 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., & Joshi, R. M. (Eds.). (2014). *Handbook of Arabic literacy: Insights and perspectives* (9 vol.). Springer Science and Business Media

Saiegh-Haddad, E., Levin, I., Hende, N., & Ziv, M. (2011). The linguistic affiliation constraint and phoneme recognition in diglossic Arabic. *Journal of Child Language*, *38*(2), 297–315. https://doi.org/10.1017/S0305000909990365

Saiegh-Haddad, E., & Schiff, R. (2016). The impact of diglossia on voweled and unvoweled word reading in Arabic: A developmental study from childhood to adolescence. *Scientific Studies of Reading*, *20*(4), 311–324. https://doi.org/10.1080/10888438.2016.1180526

Seidenberg, M. S. (1985). The time course of phonological code activation in two writing systems. *Cognition*, *19*(1), 1–30. https://doi.org/10.1016/0010-0277(85)90029-0

Seidenberg, M. S., & McClelland, J. L. (1989). A distributed, developmental model of word recognition and naming. *Psychological Review*, *96*(4), 523–568. https://doi.org/10.1037/0033-295x.96.4.523

Seymour, P. H., Aro, M., Erskine, J. M., & Seymour : PH, & Collaboration with COST Action A8 Network. (2003). Foundation literacy acquisition in European orthographies. *British Journal of Psychology*, 94(2), 143–174. https://doi.org/10.1348/000712603321661859

Share, D. L. (2008). On the Anglocentricities of current reading research and practice: The perils of overreliance on an *outlier* orthography. *Psychological bulletin*, *134*(4), 584

Taha, H. (2016). Deep and shallow in Arabic orthography: New evidence from reading performance of elementary school native Arab readers. *Writing Systems Research*, *8*(2), 133–142. https://doi.org/10.1080/17586801.2015.1114910

Taibah, N. J., & Haynes, C. W. (2011). Contributions of phonological processing skills to reading skills in Arabic speaking children. *Reading and Writing*, *24*(9), 1019–1042. https://doi.org/10.1007/s11145-010-9273-8

Van Orden, G. C., Pennington, B. F., & Stone, G. O. (1990). Word identification in reading and the promise of subsymbolic psycholinguistics. *Psychological Review*, *97*(4), 488–522. https://doi.org/10.1037/0033-295x.97.4.488

Winskel, H., & Lee, L. W. (2014). Learning to read and write in Malaysian/Indonesian: A transparent alphabetic orthography. In H. Winskel, & P. Padakannaya (Eds.), *South and Southeast Asian psycholinguistics* (pp. 179–183). Cambridge: Cambridge University Press

Yang, H. Y., & Hua, Z. (2010). The phonological development of a trilingual child: Facts and factors. *International Journal of Bilingualism*, *14*(1), 105–126. https://doi.org/10.1177/1367006909356650

Ziegler, J. C., & Goswami, U. (2005). Reading acquisition, developmental dyslexia, and skilled reading across languages: A psycholinguistic grain size theory. *Psychological Bulletin*, *131*(1), 3–29. https://doi.org/10.1037/0033-2909.131.1.3

Ziegler, J. C., Grainger, J., & Brysbaert, M. (2010). Modelling word recognition and reading aloud. *European Journal of Cognitive Psychology*, *22*(5), 641–649. https://doi.org/10.1080/09541446.2010.496263

Zorzi, M. (2010). The connectionist dual process (CDP) approach to modelling reading aloud. *European Journal of Cognitive Psychology*, *22*(5), 836–860. https://doi.org/10.1080/09541440903435621

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