Neuropsychology
2002, Vol. 16, No. 3, 322–326

0894-4105/02/$5.00 DOI: 10.1037//0894-4105.16.3.322

The Characteristics of Arabic Orthography Slow Its Processing

Raphiq Ibrahim
Rambam Medical Center and University of Haifa

Zohar Eviatar
University of Haifa

Judith Aharon-Peretz
Rambam Medical Center

The present study was designed to evaluate whether the complexity of Arabic orthography increases its perceptual load, thus slowing word identification. Adolescent Arabic speakers who mastered Hebrew as a second language completed oral and visual versions of the Trail Making Test (TMT; J. E. Parington & R. G. Lieter, 1949) in both languages. Oral TMT required declaiming consecutive numbers or alternation between numbers and letters. Visual TMT required connecting Arabic or Indian numbers and alternation between letters and numbers. Performance in Hebrew and Arabic oral TMT did not differ. Performance was significantly slower in Arabic visual TMT. These results indicate that Arabic speakers process Arabic orthography (1st language) slower than Hebrew orthography (2nd language) and suggest that this is due to the complexity of Arabic orthography.

This study was conducted to test the effects of orthography on letter and numeral processing. Previous research on reading acquisition in the Arabic language has revealed that this process is slower than it is in Hebrew (Azzam, 1984, 1993; Ibrahim & Eviatar, 2001). In skilled readers, it has been found that reaction times for visual recognition of Arabic words by Arabic speakers are longer than reaction times for Hebrew words by Hebrew speakers (Bentin & Ibrahim, 1996), English words by English speakers, and Serbo-Croatian words by Serbo-Croatians (Frost, Katz, & Bentin, 1987). When visual Arabic-word recognition was compared with visual Hebrew-word recognition in native Arabic speakers, Arabic words took longer to be recognized, although the Arabic words were recognized faster than the Hebrew words when the words were presented in the auditory modality (Ibrahim, 1998).

Roman and Pavard (1987) compared reading processes in Arabic and French bilingual individuals. By using oculomotor recording techniques they evaluated visual scanning strategies and found that although mean reading time did not differ between Arabic and French texts (note that for conveying identical content, the number of words needed in Arabic is less than in French because Arabic morphology is nonconcatenative and more dense; see later for more details), gaze duration per word was significantly longer in Arabic (342 ms) than in French (215 ms). This phenomenon also has been found in comparisons of Hebrew and English text reading, in which the morphology of Hebrew is dense and similar to that of Arabic, and English morphology is concatenative and more similar to French (Shimron & Sivan, 1994).

Regarding reading, there is a growing body of research that supports a “bottom-up” or “form-driven” approach in at least the majority of sentential contexts (Spoehr & Smith, 1973; Taft, 1985). What is meant by bottom-up processes is that the meaning and syntactic function of a word become available when an abstract sensory representation of the word contacts the representation of the word stored in the reader’s mental lexicon. Because it appears to be the case that sensory–lexical match is performed on the basis of the whole word or part of the word, the single letters are major candidates for being the access code, along with the whole word itself. The access code refers specifically to that perceptual unit that ultimately makes available all the lexical information about the word. It is not so illogical, however, to suppose that it is a letter, or combination of small letter-groupings, that forms the access code.

The effects of Arabic orthography on the very early stages of letter identification and grapheme–phoneme conversion were examined by Eviatar and Ibrahim (2002), using a lateralized consonant–vowel–consonant (CVC) identification task and a letter-matching task. In the CVC task, we presented vertically oriented CVC nonword trigrams by means of a divided visual field paradigm to the peripheral visual fields. Arabic speakers required the longest exposure duration for letter identification, English speakers the shortest duration, and Hebrew speakers intermediate duration. The lateralized letter-matching task revealed differential hemispheric abilities for Arabic and Hebrew in Arabic–Hebrew bilingual university students. The present study was designed to evaluate further the hypoth-

Raphiq Ibrahim, Cognitive Neurology Unit, Department of Neurology, Rambam Medical Center, Haifa, Israel, and Department of Psychology, University of Haifa, Haifa, Israel; Zohar Eviatar, Department of Psychology, University of Haifa; Judith Aharon-Peretz, Cognitive Neurology Unit, Department of Neurology, Rambam Medical Center.

The study was supported by funds from the Sapir Foundation of Mifaal-Hapais to Raphiq Ibrahim.

Correspondence concerning this article should be addressed to Judith Aharon-Peretz, Cognitive Neurology Unit, Department of Neurology, Rambam Medical Center, P.O. Box 9602, Haifa 31096, Israel. E-mail: jaharon@rambam.health.gov.il

esis that the complexity of Arabic orthography increases the perceptual load, thus slowing word identification in Arabic.

In Hebrew and Arabic, which are Semitic languages, all verbs and most nouns are written primarily as consonantal roots which are differently affixed and voweled to form the words of the lexicon (Berman, 1978). Most written materials do not include vowels, although there are four letters in each language that, in addition to their role in signifying specific consonants, also specify long vowels (called *matres lectionis*).

However, in some cases, it is difficult for the reader to determine whether these dual-function letters represent a vowel or a consonant. When vowels do appear (in poetry, children's books, and liturgical texts), they are signified by diacritical marks above, below, or within the body of the word. Inclusion of these marks specifies the phonological form of the orthographic string, making it completely transparent in terms of orthography–phonology relations. As the majority of written materials do not include the diacritical marks, a single printed word not only is often ambiguous among different lexical items (this ambiguity is normally solved by semantic and syntactic processes in text comprehension) but also does not specify the phonological form of the letter string. Thus, in their unpointed form, Hebrew and Arabic orthographies contain a limited amount of vowel information and include a large number of homographs. Both languages are written from right to left.

Arabic differs from Hebrew. Arabic has two forms: literary Arabic (also known as modern standard Arabic) is universally used in the Arab world for formal communication and writing (in which news is reported), and it is the language of prayer and of public occasions. Spoken Arabic refers to regional dialects and has no written form. The spoken dialect in a particular region is the native language of all native speakers of Arabic in that region, whereas literary Arabic is taught in school in parallel with reading and writing. Although sharing a limited subgroup of words, the two forms of Arabic are phonologically, morphologically, and syntactically somewhat different. For example, certain vowels (such as *e* and *o*) exist in spoken Arabic but not in literary Arabic; in spoken Arabic, words may begin with two consecutive consonants or with a consonant and a "schwa," whereas this is illegal in literary Arabic. The two forms utilize different inflections (such as plural markings) and different insertion rules for function words, and the two forms have different word-order constraints in sentence structure. Previously, we have shown that young Arab children who have been exposed to literary Arabic function as bilinguals on tests of metalinguistic awareness (Eviatar & Ibrahim, 2000) but that this metalinguistic advantage does not carry over to advantages in the acquisition of reading skills (Eviatar & Ibrahim, 2002). Although their scores on tests of phonological awareness were higher than those of monolingual Hebrew speakers, their scores on tests of reading achievement were lower. We suggested that this is due to the complexity of Arabic orthography as compared with Hebrew orthography.

Compared with English, additional complexity is found in several characteristics that occur in both orthographies but to a much larger extent in Arabic than in Hebrew. The first characteristic has to do with diacritics and dots. In Hebrew, dots occur only as diacritics to mark vowels and as a stress-marking device (dagesh). In the case of three letters, this stress-marking device (which does not appear in unvowelized scripts) changes the phonemic representation of the letters from fricatives (*v*, *x*, *f*) to stops (*b*, *k*, *p* for the letters בקפ, respectively). In the unvowelized form of the script, these letters can be disambiguated by their place in the word, as only the initial placement of a word or syllable indicates the stop consonant. In Arabic the use of dots is more extensive: Many letters have a similar or even identical structure and are distinguished only on the basis of the existence, location, and number of dots (e.g., the Arabic letters representing /t/ and /n/ [/ت/ and /ن/, respectively] become the graphemes respresenting /th/ and /b/ [/ث/ and /ب/, respectively] by adding or changing the number or location of dots).

The second characteristic of the two orthographies is that some letters are represented by different shapes, depending on their placement in the word. Again, this is much less extensive in Hebrew than in Arabic. In Hebrew there are five letters which change shape when they are word-final: (ם -מ, ן -נ, ץ -צ, ף -פ, ך -כ). In Arabic, 22 of the 28 letters in the alphabet have four shapes each (word-initial, -medial, -final, and when they follow a nonconnecting letter, e.g., the phoneme /h/ is represented by the following graphemes: ه ـه ـهـ هـ), and six have two shapes each (final and separate). Thus, grapheme–phoneme relations are quite complex in Arabic, with similar graphemes representing quite different phonemes, and different graphemes representing the same phoneme.

Arabic orthography has two sets of graphemic representations for numbers. In written materials, and for arithmetic up to third grade, the numerals used are of Indian origin, using the Hindi orthography. Students are introduced to the universal Arabic numerals in the middle of third grade and from then on use them exclusively for mathematics. However, the Hindi numerals continue to be used extensively in written Arabic materials (e.g., newspapers, books). Although the graphemic complexity of the Hindi numerals does not seem higher than that of the universally used Arabic digits (e.g., the numbers 1–10 are as follows: ١٠ ٩ ٨ ٧ ٦ ٥ ٤ ٣ ٢ ١), we tested whether this population, which has two different sets of graphemes for quantity, processes one set more efficiently than the other. In addition, given that the two graphemic systems for numbers have a different distribution in the environment, we asked whether they constitute one or two separate cognitive sets.

Method

Participants

Thirty 10th-grade students (15 boys, 15 girls; age 15) participated. All were volunteer native Arabic speakers learning in Arabic schools, in which the teaching language is Arabic and Hebrew is learned as a second language. None of the participants suffered from neurological, emotional, attentional, or learning disorders.

Materials

We used oral and visual variants of the Trail Making Test (Parington & Lieter, 1949). In the oral test, the participants declaimed the first 13 letters of the alphabet alternately with numbers from 1 to 13, once in Hebrew and once in Arabic. All of the visual versions consisted of stimuli randomly scattered on a page, and the task of the participants was to connect them in serial order. Time of completion of each task was measured. In Arabic several versions of the visual tests were created. In the numbers-only test (Arabic and Hindi numerals 1–13) and letters-only test (the first 25 letters), the task was to connect numbers and letters serially. In the letters and numbers test (Trail B), the task was to connect the letters and the Arabic numbers alternately in serial order (e.g., A, 1, B, 2). We constructed three versions of this test in Arabic, using unconnected, connected and mixed[1] letters. Because most Hebrew letters do not change in shape according to their location, in the Hebrew session the students were required merely to perform a letters-only and one letters and numbers test (Trail B) version.

Because reading involves phonological computation (the speed of uttering letter- and number-names is determined by their phonological length and structure), we compared the phonological structure of the evaluated letter-names and numbers characteristics between languages. The phonological structure of the first 13 letters and numbers in Arabic and in Hebrew revealed similar results with little advantage for Hebrew in the case of letter-names' mean syllables (1.0 vs. 1.3 for Arabic and Hebrew, respectively) and little advantage for Arabic in the case of number-names' mean syllables (2.8 vs. 2.2 for Arabic and Hebrew, respectively).

Procedure

Participants were tested individually. Each session was 40 min long. Half the participants performed the oral test first and the visual tests second, and the other half performed them in the opposite order. Within each modality, half the participants performed the Arabic tests first and then the Hebrew tests, and half performed them in the opposite order. Of the 30 participants, 10 completed each version of the Arabic letters and numbers test.

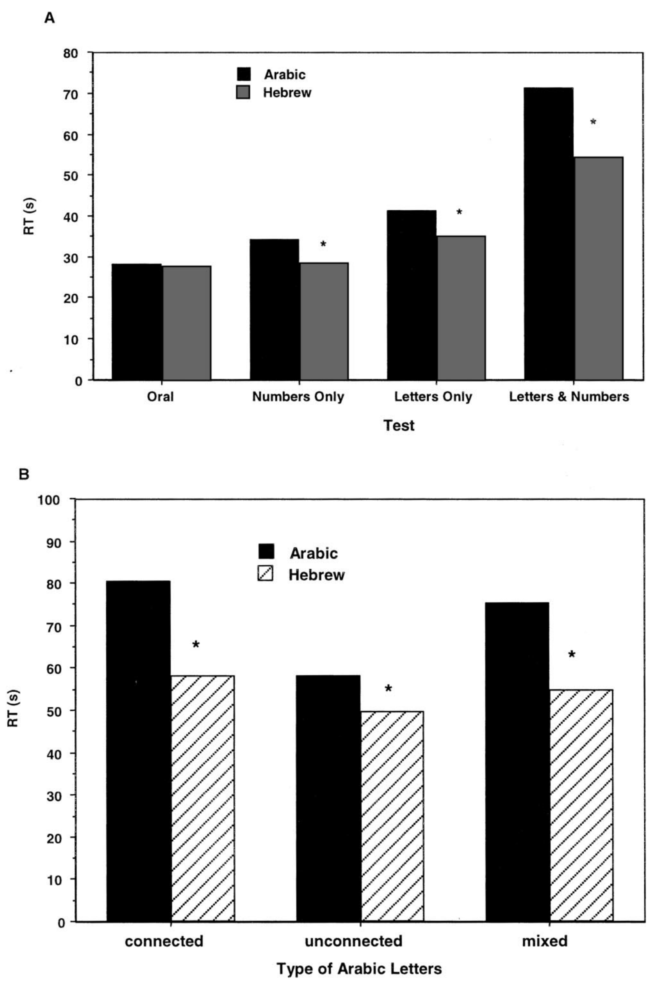

Figure 1. Panel A: The effects of language on speed of performance in versions of the Trail Making Test. Panel B: Performance on the three versions of the letters and numbers (Trail B) test. An asterisk indicates a significant effect. RT = response time.

Results

We analyzed the time measured to complete each version of the test using a 2 × 4 analysis of variance (ANOVA), with Language (Hebrew vs. Arabic) and Test (oral, visual letters only, visual numbers only, and visual letters and numbers) as within-subject factors. Both main effects were significant: Language, $F(1, 29) = 33.24$, $p < .001$; Test, $F(3, 87) = 132.28$, $p < .001$, as was the interaction between them, $F(3, 87) = 17.84$, $p < .001$. These effects are illustrated in Panel A of Figure 1. Planned comparisons revealed that language had no effect in the oral version ($p > .36$), whereas performance in Hebrew was significantly faster than in Arabic in all of the visual tests: letters only, $F(1, 29) = 12.59$, $p < .001$; numbers only, $F(1, 29) = 19.46$, $p < .0001$; letters and numbers, $F(1, 29) = 31.80$, $p < .0001$.

We performed an additional ANOVA on the letters and numbers test to explore the effects of the types of Arabic letters on the difference between the Arabic and Hebrew versions of the test. Recall that there were three types of Arabic versions of this test, one with letters represented in their unconnected form (e.g., /h/: ه), one with letters represented in their connected form (e.g., /h/: ـهـ), and one in which these forms were mixed (both types of forms occurred). This manipulation was not done on the Hebrew versions, such that they were identical in the three conditions. The analysis revealed a main effect of Language, $F(1, 27) = 34.54$, $p < .0001$, a main effect of Type of Arabic Letter, $F(2, 27) = 6.66$, $p < .005$, and no interaction between them, $p > .12$. As can be seen in Panel B of Figure 1, although performance on the unconnected-letters version was significantly faster than on the other versions, $F(1, 27) = 13.00$, $p < .005$, all three types of Arabic letters

[1] *Mixed*: To manipulate the factor of connected-unconnected, we created a version in which half of the letters appeared in the connected form and the other half appeared in the unconnected form.

resulted in slower completion times than the Hebrew version of the test. The Hebrew versions represent the same type of Hebrew orthography but in different groups. Post hoc comparison showed that the differences in the Hebrew conditions are not significant.

We computed correlation coefficients between the different versions of the tests within each language and across the languages. The relationships between the tests within the languages are illustrated in Tables 1 and 2. Table 1 presents the intercorrelations between the tests in the Hebrew language and presents the same relationships in the Arabic language, and Table 2 presents the intercorrelations of the tests between the two languages. The salient findings are that the intercorrelations in Hebrew are much weaker and smaller than in Arabic (e.g., the oral version of the test is not related to performance on the visual tests in Hebrew and is significantly related to performance on the visual tests in Arabic). Interestingly, although performance on the oral tests in the two langauges is almost perfectly correlated, the correlations between performance on the visual tests in Hebrew and in Arabic are small or nonexistent.

To test the hypothesis that the two graphemic systems for numbers result in separate cognitive sets, we compared the response times of the numbers (Trail B) with the response times for each type of number alone (numbers only in both languages), and with the letters and numbers (Trail B) version in the two languages, using planned comparisons. It can be seen that the shortest response times ocurred in the conditions where only one number type appeared—either the universal Arabic numerals alone (28.50 s, $F[1, 116] = 101.61$, $p < .0001$) or the Hindi numerals alone (34.23 s, $F[1, 116] = 57.49$, $p < .0001$). Both were significantly faster than the version containing both types of numerals (the numbers [Trail B], 51.63 s). Interestingly, the numbers (Trail B) test was not significantly different from the Hebrew (Trail B) test (54.37 s, $p > .23$) but was significantly faster than the Arabic (Trail B) test (71.40 s, $F[1, 116] = 57.49$, $p < .0001$). Thus, the combination of Arabic letters and Hindi numerals resulted in the slowest processing times.

Table 1
Intercorrelations of Tests in Hebrew and in Arabic

Test	Oral	Numbers only	Letters only
	r, p	*r, p*	*r, p*
Hebrew tests			
Numbers only	*ns*, > .90		
Letters only	*ns*, > .90	.56, < .01	
Letters and numbers	*ns*, > .80	.36, = .05	.43, < .05
Arabic tests			
Numbers only	.44, < .05		
Letters only	.43, < .05	.59, < .01	
Letters and numbers	.36, = .05	.51, = .01	.52, < .01

Note. $n = 30$.

Table 2
Intercorrelations of the Tests Between Languages

Hebrew tests	Arabic tests: Oral	Numbers only	Letters only	Letters and numbers
	r, p	*r, p*	*r, p*	*r, p*
Oral	**.96, > .0001**	.35, = .06	*ns*, > .09	*ns*, > .20
Numbers only	*ns*, > .70	**.40, < .05**	*ns*, > .18	*ns*, > .25
Letters only	*ns*, > .36	*ns*, > .08	***ns*, > .10**	.34, = .07
Letters and numbers	*ns*, > .90	*ns*, > .12	*ns*, > .16	**.35, = .06**

Note. Relationships between the same test in the two languages are in bold.

Discussion

Comparing Arabic word-recognition times with Hebrew (Bentin & Ibrahim, 1996), English, and Serbo-Croatian word-recognition times (Frost et al., 1987), we noticed that it took longer to process words in Arabic relative to the other languages. Our hypothesis in this research was that the complexity of Arabic orthography increases the perceptual load, thus slowing word identification in Arabic. Indeed, and in accordance with our hypothesis, the present study of highly proficient bilinguals reveals that Hebrew letters are processed faster than are Arabic letters and that universal Arabic numerals are processed faster than are Hindi numerals. Oral performance times are equal in the two languages, supporting the hypothesis that the participants are equally adept at reciting the Hebrew and Arabic alphabets and the names of numbers in both languages. The fact that the phonological structure is similar across languages suggests that the difference in visual letter and number processing between Hebrew and Arabic is primarily influenced by visual or orthographic and not by phonological factors.

The results of the letters-only tests support the hypothesis that the visual complexity of Arabic letters results in an increased processing load, thus slowing performance in Arabic in comparison with performance of the same task in Hebrew. Theoretically, some of the slowness in processing may stem from a conflict at the access to phonological codes (reflected by difficulties at the production stage) caused by the interference between spoken and literary Arabic. However, this possibility has already been tested (controlled) in a previous study (Bentin & Ibrahim, 1996, Experiment 2A) in which (showing) similar reaction times for spoken and literary Arabic in a delayed naming task were found.

This finding joins the list of studies mentioned previously that have all found evidence for cumbersome processing of the Arabic orthography and are congruent with the studies of McCusker, Hillinger, and Bias (1981), who suggested that three factors influence the relative time course of orthographical and phonological code activation in word recognition: the participant's reading ability, the task demands, and the complexity of the stimuli. The present study did not involve students with known reading difficulties, and the task demands were identical in all conditions. As already mentioned, the Hebrew versions represent the same type of Hebrew orthography but in different groups. Post hoc comparison showed that the differences in the Hebrew conditions are not significant, suggesting that the effect totally accounts for the stimulus-type effect in Arabic.

Interestingly, we also found an effect of language in the numbers-only test. Here we compared the speed at which the participants serially connected randomly scattered numerals. The Hebrew condition used the universally used Arabic digits, whereas the Arabic condition used the Hindi digits. We showed that performance with the universal Arabic digits is faster than with the Hindi digits. Here our hypothesis about graphemic complexity may not hold, and we interpreted the results as reflecting differences in the frequency with which the participants encounter the two types of digits. Our Arabic speakers are bigraphemic for numbers, as they have two different graphemic systems for the same concepts. As mentioned previously, the distribution of these systems is different: The universal digits are used for mathematical computations, whereas the Hindi digits are used in the context of written materials. We hypothesized that these different frequency distributions result in the formation of separate cognitive sets for the two types of numerals. This hypothesis was supported by the results of the comparisons between the numbers (Trail B) test and the other tests shown in Table 2. The findings suggest that the two types of graphemic systems are represented in different sets, such that alternating between them resulted in slower responses than with either type of numeral alone.

These findings also support our major conclusion that Arabic letters are harder to identify than Hebrew letters as a result of their greater visual complexity, because although our participants encounter Hindi numerals less frequently than universal Arabic numerals, their performance on the Hindi numerals alone was significantly faster in this task than on either of the Trail B tasks, both in Hebrew and in Arabic. That is, the fact that these stimuli are relatively infrequent did not result in slower processing, as these are not visually more complex than universal Arabic numerals.

Our conclusion is that the source of slower performance times in Arabic is due to difficulties in decoding the complex visual orthography of letters. Our results have important implications regarding didactic methods of the teaching of the Arabic orthography in early childhood and about the validity of tests that involve Arabic script in native Arabic-speaking populations.

References

Azzam, R. (1984). Orthography and reading of the Arabic languge. In J. Aaron & R. M. Joshi (Eds.), *Reading and writing disorders in different orthographic systems* (pp. 1–29). Kluwer Academic.

Azzam, R. (1993). The nature of Arabic reading and spelling errors of young children. *Reading and Writing, 5,* 355–385.

Bentin, S., & Ibrahim, R. (1996). New evidence for phonological processing during visual word recognition: The case of Arabic. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22,* 309–323.

Berman, R. A. (1978). *Modern Hebrew structure.* Tel Aviv, Israel: University.

Eviatar, Z., & Ibrahim, R. (2000). Bilingual is as bilingual does: Metalinguistic abilities of Arabic-speaking children. *Applied Psycholinguistics, 21,* 451–471.

Eviatar, Z., & Ibrahim, R. (2002). *Orthography and the hemispheres: The case of Arabic script.* Manuscript in preparation.

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,* 104–114.

Ibrahim, R. (1998). *The cognitive representation of literate and spoken Arabic languages: A comparison within and between languages.* Unpublished doctoral dissertation, Hebrew University of Jerusalem, Israel.

Ibrahim, R., & Eviatar, Z. (2001). *The effects of metalinguistic awareness on the acquisition of reading: A cross-language comparison.* Manuscript submitted for publication.

McCusker, L. X., Hillinger, M. L., & Bias, R. C. (1981). Phonological recoding and reading. *Psychological Bulletin, 89,* 217–245.

Parington, J. E., & Lieter, R. G. (1949). Parington's pathway test. *The Psychological Service Center Bulletin, 1,* 9–20.

Roman, G., & Pavard, B. (1987). A comparative study: How we read Arabic and French. In J. K. O'Regan & A. Levy-Schoen (Eds.), *Eye movement: From physiology to cognition* (pp. 431–440). Amsterdam, the Netherlands: North Holland Elsevier.

Shimron, J., & Sivan, T. (1994). Reading proficiency and orthography: Evidence from Hebrew and English. *Language Learning, 44,* 5–27.

Spoehr, K. T., & Smith, E. E. (1973). The role of syllables in perceptual processing. *Cognitive Psychology, 5,* 71–89.

Taft, M. (1985). The decoding of words in lexical access: A review of the morpho-graphic approach. *Reading Research: Advances in Theory and Practice, 5,* 83–120.

Received May 2, 2001
Revision received November 26, 2001
Accepted January 16, 2002 ■