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Morphological and orthographic effects on hemispheric processing of nonwords: A cross-linguistic comparison

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Abstract. We tested the effects of morphological and orthographic differences between English, Hebrew, and Arabic on the functioning of the two cerebral hemispheres. University students who were native speakers of each of the three languages performed a lateralized consonant-vowel-consonant (CVC) identification task. The stimuli were presented vertically in three conditions: left visual field (LVF), right visual field (RVF), and bilaterally (BVF). Three dependent measures were used: (1) exposure duration of the stimuli in order to achieve a 50% error rate, (2) total number of errors in each presentation condition and (3) the difference between errors on the first letter and errors on the last letter, a qualitative measure of sequential processing. Arabic readers required longer exposure durations of the syllables in order to achieve a 50% error rate than Hebrew readers, who in turn, required longer exposure durations than native English readers. Readers of all three languages evinced left hemisphere specialization for this linguistic task and a bilateral advantage. The qualitative patterns revealed that the Arabic and Hebrew speakers showed the same hemispheric difference pattern, that was different from the one shown by English readers, and that Arabic readers showed a qualitative pattern suggesting higher levels of sequential processes in both hemisphere than readers of Hebrew and English. We interpret this as reflecting the adaptation of hemispheric abilities to reading languages that differ in morphological structure and orthography.

Key words: Cross-Language, Hemispheric Specialization, Morphology, Orthography, Reading

Introduction

The convergence and divergence of patterns shown by participants with different language backgrounds is crucial to our attempt to develop a model of the way in which the functioning of the human brain results in higher cognitive functions. The focus here is on the manner in which principled differences in learned behaviors co-occur with systematic differences in the functional architecture of cognitive functions in the cerebral hemispheres. Specifically, we look at the demands made upon the cognitive system to read a language with a particular structure, encoded in a particular orthography. The vast majority of research on the neuropsychological underpinnings of reading is done with English speakers reading English. It is therefore necessary to examine patterns shown by users of other languages to test our general model of brain functioning during reading. The experiment described below explored the effects of morphology and orthography on hemispheric functioning in the very early stages of reading, by comparing patterns of performance in a lateralized task of native readers of Arabic to those revealed by readers of a somewhat similar language, Hebrew, and a very different language, English.

Characteristics of Arabic and Hebrew

In Hebrew and Arabic, which are Semitic languages, all verbs and most nouns are written primarily as consonantal roots that 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 which, in addition to their role in signifying specific consonants, also specify long vowels (these are 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 completely 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 is often not only ambiguous between 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, the 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 in interesting ways. Arabic has two forms: Literary Arabic (also known as Modern Standard Arabic) is universally used in the Arab world for formal communication and writing. Spoken Arabic is a local dialect that has no written form. The spoken dialect is the native language of all native speakers of Arabic, while Literary Arabic is taught in school in parallel with learning to read and write. 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. As Spoken Arabic has no written form, Literary Arabic becomes part of everyday life: it is the language in which news is reported (both written and oral) and it is the language of prayer and of public occasions. 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 (Ibrahim & Eviatar, submitted). Although their scores on tests of phonological awareness are higher than those of monolingual Hebrew speakers, their scores on tests of reading achievement are lower. We suggested that this is due to the complexity of Arabic orthography as compared to Hebrew orthography.

This added complexity is found in several characteristics that occur in both orthographies, but to a much larger extent in Arabic than in Hebrew. The first 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 פ ק ב respectively). In the unvowelized form of the script these letters can be disambiguated by their place in the word, as only word or syllable initial placement 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 , ن) become the graphemes representing /th/ and /b/ (ث , ب) 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 that 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; for example, the phoneme /h/ is represented by the graphemes: ه ـه ـهـ هـ), and six have two shapes each, final and separate.

Thus, the grapheme–phoneme relations are quite complex in Arabic, with similar graphemes representing quite different phonemes, and different graphemes representing the same phoneme. Ibrahim, Eviatar, and Aharon-Perez (2002) have shown that adolescent native Arabic–Hebrew bilinguals process Hebrew letters faster and more accurately than Arabic letters. Eviatar, Ibrahim and Ganayim (2004) investigated the abilities of the cerebral hemispheres of native Arabic and Hebrew speakers to visually match letters in Arabic and in Hebrew (The Arabic speakers could all read Hebrew, but the Hebrew speakers could not read Arabic). The Hebrew speakers showed equivalent performance in the two visual fields in both Hebrew and Arabic: good performance in Hebrew, because both hemispheres can do the letter matching task (e.g., Eviatar & Zaidel, 1992), and poor performance in Arabic, because the letters were unfamiliar and hard to discriminate. The Arabic speakers revealed a fascinating pattern: in Hebrew their responses were equivalent to those of the Hebrew speakers in both visual fields. That is, as with the Hebrew readers, both hemispheres of Arabic speakers can identify and match letters in Hebrew. However, in Arabic, in the RVF, performance was equivalent to performance in Hebrew (e.g., the left hemisphere of these participants identifies Hebrew and Arabic letters with the same skill). In the LVF, however, Arabic speakers showed performance equivalent to that of the Hebrew speakers, those who do not read Arabic. Thus, the right hemisphere of these participants cannot identify letters in Arabic, even though it can identify letters in Hebrew. An additional experiment supported the hypothesis that this is because often, the only distinguishing characteristics of different letters in Arabic are changes at the element level of the letters, such as the placement or number of dots, and the right hemisphere (RH) is less sensitive to these aspects of the letters than is the left hemisphere.

How may these differences affect hemispheric functioning in reading Arabic? The experiment reported here extended the exploration of the effects Arabic orthography on the very early stages of letter identification by using a task that also requires grapheme–phoneme conversion. The experimental task consists of presenting vertically oriented consonant-vowel-consonant (CVC) nonword trigrams via a divided visual field paradigm to the peripheral visual fields. The stimuli are presented unilaterally to the right (RVF) and to the left (LVF) visual fields, and also bilaterally in both visual fields simultaneously (The BVF condition). Stimuli in the RVF are initially encoded by the left hemisphere (LH), those in the LVF are initially available only to the RH, and those in the BVF are available to both hemispheres simultaneously. The participants are asked to pronounce the stimulus aloud, and to identify its constituent letters. Requiring pronunciation ensures that the participant computed the grapheme–phoneme conversion of the letters, and the accuracy of the letters identified in the three visual field conditions is scored. The task was developed by Levy, Heller, Banich, and Burton (1983) and used extensively by Hellige and his colleagues to explore both hemispheric functions and interhemispheric interaction (e.g., Hellige, Taylor & Eng, 1989; Hellige et al., 1994). Processing of the stimuli is indexed by analyzing the number and types of errors made in identifying the letters in each visual presentation condition. This task is especially useful because it yields three types of data: (1) In order to induce participants to make many errors, exposure duration of the stimuli is titrated in 15 ms steps, on each trial, for each participant. Therefore, the median exposure duration for each participants is an index of their ability to discriminate the letters, at a level of 50% accuracy, (2) The percent error rate in each visual field is an index of hemispheric specialization for the task, with the BVF condition revealing processing efficiency when both hemispheres have access to the stimulus, and (3) the types of errors made by the participants are analyzed as a qualitative index of the type of processing that occurs in each condition. The errors are classified into three categories: First Errors (FEs) are defined as errors on the first letter of the CVC when the last letter is reported correctly (irrespective of the accuracy of the vowel). Last Errors (LEs) are defined as errors on the last letter when the first is reported correctly (again ignoring the correctness of the vowel). All other errors (such as errors only on the vowel or all three letters reported incorrectly) are classified as Other Errors (OEs). This classification is made separately for responses in each of the visual presentation conditions, and the data are normalized such that each error category represents the percentage of those types of errors in a particular visual field. This is done to clarify the error patterns, as there is a consistent RVFA in errors for this linguistic task, whereas the measure of interest is the difference between the relative proportion of FEs and LEs in each of the visual fields.

Previous studies using English (e.g., Hellige & Cowin, 1996; Hellige et al., 1988) have reported an asymmetry in this qualitative measure, indicating a larger difference between normalized FEs and LEs in the LVF(RH) than in the RVF(LH). This difference has been interpreted as an index of processing style: a large difference indicates a sequential strategy, whereas a small difference indicates a more parallel processing strategy. The interpretation has been that the LH processes the syllable as a unit, and thus makes a similar amount of errors on the first and the last errors, whereas the RH processes the trigrams letter by letter, and thus makes many more errors on the last letter (LEs) than on the first letters (FEs). Eviatar (1999) reported that readers of Hebrew reveal the same RVFA in errors, but show the opposite asymmetry from English speakers in normalized FEs and LEs. This difference persisted when the stimuli were in English (for the Hebrew speakers) and in Hebrew (for the English speakers), and when the stimuli were identical for speakers of the two languages (number trigrams). She concluded that this qualitative difference in hemispheric functioning is a result of reading strategies that are constrained by the orthographic and morphological characteristics of the native language of the participants. These strategies are also used when reading a second language, where they may not be optimal, by these moderately fluent bilinguals. The experiment presented below was performed with native Arabic speakers performing the task in Arabic. The data are compared to native Hebrew and English speakers, each performing the task in their own native language.

Method

Design. The paradigm yielded three dependent variables. The first is median exposure duration. In order to achieve a 50% error rate, exposure duration of the stimuli was titrated in 15 ms intervals after each trial. If the participant made an error, the next stimulus was shown for 15 ms longer. If the participant reported all three letters correctly, exposure duration was titrated down by 15 ms. This computation was automated by the computer. The maximum exposure duration was 210 ms. We computed the median exposure duration for each participant in each visual field. The second dependent variable is Total Errors (TE), which is the percentage of errors (out of 36) in each visual field. This measure indicates the quantitative differences between the visual presentation conditions. The third dependent measure is qualitative, where error categories were calculated separately for each visual field as the number of each type of error (FE or LE). We computed a Qualitative Error score (QE) in the following manner: QE = (LE–FE)/TE (where LE = number or errors on the last letter when the first letter was reported correctly; FE = number of errors on the first letter when the last letter was reported correctly; TE = total number of errors in that VF).

The dependent variable exposure duration was analyzed with a 1-way between groups ANOVA using Native Language as the independent variable. Analyses of TEs and QEs utilized a mixed design: Native language (Arabic, Hebrew, English) was a between-groups variables, and Visual Field (LVF, RVF, BVF) was a within-groups variable.

Participants. Sixty University of Haifa students were tested (20 in each language group). All received either course credit or 15 NIS (an equivalent of $5) for their participation. All were right-handed and neurologically normal.

Stimuli and Procedure. The stimuli in all language conditions were 37 vertically presented CVC trigrams created from a set of 15 letters. In English the first and third letter of the trigrams were chosen from the set of 12 consonants: B, C, G, D, J, K, T, S, P, M, V, Z, and the middle letter from 3 vowels: A, O, and E. All were capitals, in Helvetica-Bold Font 16. In Hebrew the first and third letter of the trigrams were chosen from the set: ב,ג,ד,ז,ח,ט,כ,ל,מ,ס,פ and the middle letter was always ו,י or א which often double as vowels, in Maariv-B40 Font 18. In Arabic the first and third letters were chosen from the set ي، ش، ج، ن، ز، و، م، ل، ف، ع، ط، س، ر، ح، ث، ب, and the middle letter was always ي، و، or ا . The letters were hand written and scanned and digitized. All of the letters were presented in their unconnected form. None of the trigrams in Hebrew or Arabic included diacritical marks that can specify the form of the vowel, or word-final forms of the graphemes. All of the letters subtended 0.5 × 0.5 degrees of visual angle. All stimuli were presented vertically, with their inner edge 1.5° of visual angle from fixation. The trigrams subtended 0.5° horizontally and 2° vertically. The experimental trials were presented in three blocks of 37 trials where the first trial was not scored. Across blocks, each item appeared once in each visual presentation condition. Order of the trials was pseudo-random, with the constraint that each presentation condition preceded the others an equal number of times. Participants completed 37 trials as practice before beginning the experimental trials. The order of events on each trial was the following: a 1000 Hz tone sounded to alert the participant that the trial was beginning, a fixation cross appeared for 2 s, then the stimuli were shown for the appropriate duration. A bilateral pattern mask consisting of horizontal lines appeared for 200 ms immediately after the stimulus. The participant pronounced the syllable, and then spelled it. The experimenter typed the participants' response into the computer, and after 2 s, the next trial began. Because the Hebrew and Arabic stimuli were unvoweled, some of the trigrams were phonologically ambiguous, however, the pronunciaton of the trigram was not recorded, only the spelling provided by the participants was used as data. The experiment was run on a Silicon Graphics workstation, model Personal Iris 4D30, which also collected the responses.

Results

Exposure duration

The mean median exposure durations needed to achieve a 50% error rate by the language groups are illustrated in Figure 1. It can be clearly seen that Arabic speakers required the longest exposure durations and that English speakers required the shortest exposure durations. The main effect of language is significant, $F(1,57) = 155.75$, $P < 0.0001$, as are all two way comparisons between the groups ($P < 0.0001$).

Total errors

The percent-errors in each visual field for the three language groups are illustrated in Figure 2. A mixed ANOVA revealed a significant main effect of visual field, $F(2,114) = 74.13$, $P < 0.0001$; a significant main effect of language group, $F(2, 57) = 17.92$, $P < 0.0001$, and a significant interaction between them, $F(4,114) = 5.30$, $P < 0.001$. As can be seen in the Figure, in the LVF, Arabic speakers made significantly more errors than the other two language groups (Arabic speakers vs. Hebrew speakers, $F(1,57) = 7.12$, $P < 0.01$; Arabic speakers vs. English speakers, $F(1,57) = 12.08$, $P < 0.005$), whereas in the RVF, Hebrew speakers make significantly more errors than the other two language groups (Arabic speakers vs. Hebrew speakers ($F(1,57) = 12.77$, $P < 0.001$; English speakers vs. Hebrew speakers, $F(1,57) = 29.84$, $P < .0001$), and in the BVF, the only significant difference is between English and Arabic speakers, $F(1,57) = 5.52$, $P < 0.05$.

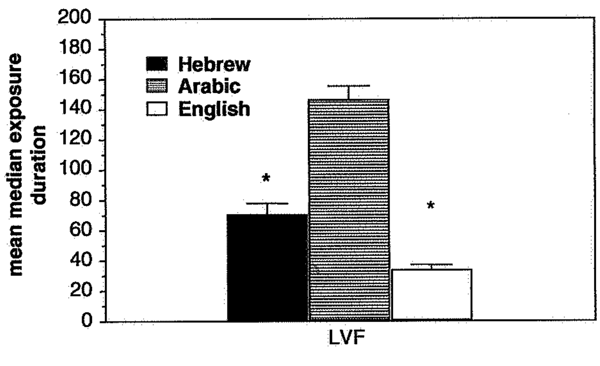

Figure 1. Mean median exposure durations of the stimuli to achieve a 50% error rate in each of the three language groups. Significant differences ($P < 0.05$) are indicated by an *.

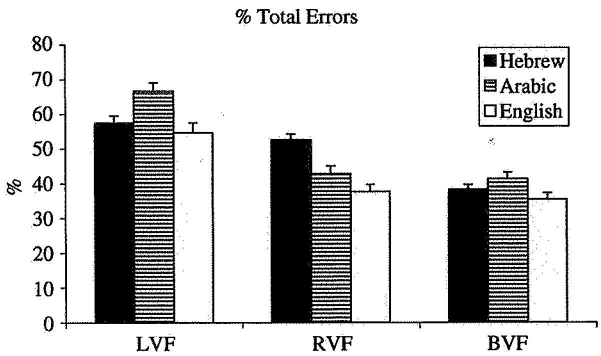

Figure 2. Percent error rate in each visual field condition in each of the language groups. All show a visual field advantage, indicating LH specialization for the task.

All three groups revealed the expected RVFA, and a bilateral advantage. That is, all groups made less errors in the RVF than in the LVF, and less errors when they saw the stimuli bilaterally than unilaterally. It can be seen that the RVFA is greatest for the Arabic speakers. Planned comparisons reveal that the RVFA shown by the Arabic speakers (23.75%) is significantly larger than the RVFA shown by Hebrew speakers (4.86%, $F(1,57) = 14.23$, $P < 0.0005$), while the RVFA shown by the English speakers (16.94%), does not differ significantly from either of the other groups ($P > 0.17$).

Qualitative error patterns

In order to examine hemispheric processing strategies, we computed a QE score as defined by Levy et al. (1983) in the following manner: QE = (LE–FE)/TE for each participant in each visual field. That is, the normalized (for TE) difference between LEs and FEs. A large QE indicates serial processing, as it results from many more errors on the last letter than on the first letter, whereas a smaller QE indicates more parallel processing, where participants make similar rates of errors on first and last letters. These data are illustrated in Figure 3. As can be inferred from the figure, a 2-way mixed ANOVA revealed a main effect of each of the factors (Language: $F(2,57) = 12.48$, $P < 0.0001$; Visual Field: $F(2,114) = 11.88$, $P < 0.0001$) and an interaction between them, $F(4,114) = 10.07$, $P < 0.0001$. Planned comparisons revealed different patterns in the visual presentation conditions: in the bilateral condition, Arabic readers had significantly higher QE scores than both the Hebrew readers ($F(1,57) = 13.14$, $P < 0.001$) and English readers ($F(1,57) = 40.62$,

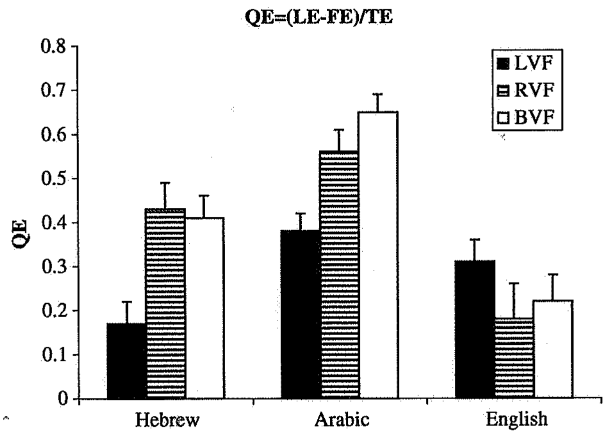

Figure 3. QE (qualitative error) scores in each visual field for each language group. QE scores are the normalized difference between errors on the first letter of the CVC (FEs) versus errors on the last letter (LEs), and thus index sequential processing. Thus QEs are computed separately within each visual field condition as QE = (LE–FE)/TE). The pattern of the English speakers, indicating more sequential processing in the LVF than in the RVF, is significantly different from the patterns evinced by the Hebrew and Arabic speakers, who show the opposite pattern.

$P < 0.0001$), and Hebrew readers had higher QE scores than English readers, $F(1,57) = 7.55$, $P < 0.01$. In the LVF, Arabic readers had higher QE scores than Hebrew readers, $F(1,57) = 11.53$, $p < 0.001$, but not from English readers ($P > 0.2$), and English readers also differed from Hebrew readers ($F(1,57) = 4.93$, $P < 0.05$). In the RVF, Arabic and Hebrew readers had equivalent scores ($P > 0.12$), and both had higher scores than English readers (Arabic vs. English, $F(1,57) = 18.85$, $P < 0.0001$; Hebrew vs. English, $F(1,57) = 7.76$, $P < 0.01$).

We are particularly interested in the differences in QEs between the two unilateral visual fields, as this is an indication of differences in hemispheric functioning during the processing of the CVC trigrams. We therefore computed a QE difference score (LVF_{QE}–RVF_{QE}) and compared this difference among our language groups. As reported previously in Eviatar (1999), Hebrew and English readers evince opposing patterns, $F(1,57) = 21.77$, $P < 0.001$, with English speakers revealing higher QE scores in the LVF than in the RVF, and Hebrew speakers showing higher QEs in the RVF than in the LVF. As seen in Figure 3, the pattern in the Arabic reading group is the same as for the Hebrew readers, $P > 0.33$, and they also differ significantly from the English readers, $F(1,57) = 13.71$, $P < 0.001$.

Discussion

The results of this experiment are the following: Arabic readers require longer exposure durations of the CVC syllables in order to achieve a 50% error rate than Hebrew readers, who in turn, require longer exposure durations than native English readers. In addition, readers of all three languages evince better performance when the stimuli are presented directly to the RVF/LH than to the LVF/RH, suggesting that the left hemisphere of all of these right handed participants is specialized for this linguistic task. All three groups reveal a bilateral advantage as well, reflecting better performance when both hemispheres see the stimulus than when only one stimulus is presented. Finally, the qualitative patterns reveal two findings. The first is that the Arabic speakers show the same hemispheric difference patterns as do Hebrew readers, and these are different from those shown by English readers (see Figure 3). The second is that Arabic readers have the highest QE scores among the three groups. These are discussed separately below.

Differences between English and the two Semitic languages

As mentioned in the Introduction, the difference in QE scores between visual presentation conditions is considered an indication of differences in hemispheric processing of the CVC trigrams. The ubiquitous finding with readers of English, that has been replicated here, is that the QE score, indicating a letter-by-letter processing strategy, is higher in the LVF than in the RVF. This is taken to indicate that the RH used a more serial strategy, while the LH used a more parallel strategy, in processing the CVCs. Eviatar (1999) discussed the reasons for the flipping of this pattern in Hebrew readers, suggesting that the nonconcatenative morphological structure of Hebrew, together with phonological uncertainty arising as a result of the absence of vowel information in Hebrew orthography, result in specific demands when participants are required to pronounce nonwords.

English speakers performing English versions of this task revealed similar patterns when the stimuli were presented vertically and horizontally (Hellige & Cowin, 1996), with smaller QE scores in the RVF than in the LVF. Hebrew speakers, on the other hand, showed very different patterns: with vertical stimuli, QE scores were larger in the RVF than in the LVF, and with horizontal stimuli, QE scores were nonexistent in both visual fields (Eviatar, 1999). This finding was interpreted as supporting the hypothesis that nonwords (and words) in Hebrew are not normally read in a letter-by-letter fashion by either hemisphere. This is because unvoweled nonwords in Hebrew can only be pronounced after they are compared to real words that they resemble, and the phonological form of the real words is transferred to the nonwords. Thus, naming the CVC trigrams required lexical access in Hebrew, but not in English. Lexical access in Hebrew has been shown to involve the extraction of the root (Frost & Bentin, 1992), and this extraction requires transgraphemic information (Koriat & Norman, 1985). This information is extremely hard to extract from the type of vertical presentations used here. The finding of the same pattern in readers of Arabic, which is similar to Hebrew in its morphology and in the absence of vowel information in orthography, supports and extends this hypothesis.

Eviatar (1999) also proposed that Hebrew letters are less discriminable than English letters. The results presented here suggest that Arabic letters are harder to discriminate than Hebrew letters, as they required exposure durations twice as long as those required by Hebrew readers to make the same percentage of errors. We believe that this is a result of two factors. The first is the complicated grapheme/phoneme relations in Arabic that was described in the introduction; recall that the same basic structure but with differently located dots represents different phonemes, while the same phoneme is represented by different graphemes, depending on its place in the word (initial, middle or final), and upon the letters preceding or following it. That is, there are rules about which letters are connected before and after other letters (see Ibrahim et al., 2002). The second factor has to do with the way the Arabic stimuli were constructed: we used the unconnected version of all the letters in the creation of the stimuli, irrespective of how they would be written if the syllable was presented horizontally, in the canonical manner. Nonwords in English and to a lesser extent in Hebrew, created possible orthographic patterns, whereas the stimuli in Arabic were orthographic sequences impossible in written Arabic. This must have made the task more difficult, and farther removed from normal reading, than did the vertical presentation of the trigrams in English, and even in Hebrew, where all but five letters maintain their shape, no matter where they are positioned in the word, or which letters precede or follow them. This is probably also the reason that Arabic speakers showed the largest indication of serial processing (a high QE score) in the bilateral condition. They are the only group to show such a strategy significantly more in the bilateral than in the unilateral conditions.

An interesting finding is the difference in RVFA between the groups. As seen in Figure 2, both Arabic and English readers made significantly less errors when the stimuli were presented in the RVF (directly to the LH) than when they were presented to the LVF (directly to the RH).

Hebrew readers show a difference in the same direction, but it is not as large. In the LVF, Arabic speakers made significantly more errors than the other groups, which did not differ from each other. In the RVF, it is the Hebrew speakers who made more errors than the other two groups, which did not differ from each other. We believe that the difference here between readers of Hebrew and of Arabic is due to the characteristics of Arabic orthography.

The effects of orthography

The processing of orthography has two aspects: orthography is a representation of linguistic units (e.g., phonemes in alphabetic scripts, syllables in logographic scripts), and also has purely visual aspects. This dual characteristic has colored the research on reading in general, with differing weights given to the linguistic and the visual aspects of the task [e.g., controversies about the etiology of developmental dyslexia revolve around such distinctions (e.g., Stein & Walsh, 1997)]. The investigation of the reading abilities of the two cerebral hemispheres has often identified the linguistic aspect of reading with the left hemisphere, and the visual aspect of reading with the right hemisphere (e.g., Marsolek, Kosslyn & Squire, 1992). As described in the introduction, Eviatar et al. (2004) have shown that there are large differences in the ability of the cerebral hemispheres in their ability to identify letters in Arabic, whereas there are no differences in the ability of the same hemispheres to identify letters in Hebrew (as in English). Recall that we showed in that study, that this is due to the relative insensitivity of the right hemisphere to the number and location of dots, when these are the critical difference between letters. The sample of Arabic speakers tested in this study was chosen from the same population as the samples in the study where these bilinguals performed the tasks in both Arabic and in Hebrew. We therefore believe that the long exposure duration and the large RVFA shown by our Arabic-speakers are due to the nature of the Arabic orthography, and not to a characteristic of the sample.

Conclusions

The findings reported here reflect the interaction between the inherent human pattern of hemispheric specialization for reading, and specific characteristics of languages and orthographies. A large number of studies have examined the effects of biological factors, such as gender and handedness, on the manner in which cognitive functions are organized in the cerebral hemispheres. The type of research reported here emphasizes the importance of learned behaviors as modifiers of these patterns on the one hand, and the limitations that the genetic patterns put upon our ability to learn, on the other.

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