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Language Status and Hemispheric Involvement in Reading: Evidence From Trilingual Arabic Speakers Tested in Arabic, Hebrew, and English

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This study explores the effects of language status on hemispheric involvement in lexical decision. The authors looked at the responses of native Arabic speakers in Arabic (L1 for reading) and in two second languages (L2): Hebrew, which is similar to L1 in morphological structure, and English, which is very different from L1. Two groups of Arabic speakers performed lateralized lexical decision tasks in the three languages, using unilateral presentations and bilateral presentations. These paradigms allowed us to infer both hemispheric specialization and interhemispheric communication in the three languages, and the effects of language status (native vs. nonnative) and similarity on hemispheric patterns of responses. In general the authors show an effect of language status in the right visual field (RVF), reflecting the greater facility of the left hemisphere (LH) in recognizing words in the participant's native Arabic than in their other languages. The participants revealed similar patterns of interhemispheric integration across the languages, with more integration occurring for words than for nonwords. Both hemispheres revealed sensitivity to morphological complexity, a pattern similar to that of native Hebrew readers and different from that of native English readers.

Keywords: hemisphere, lexical decision, Arabic speakers, morphology, bilinguals

The examination of hemispheric division of labor while people read different languages provides a rich framework within which to examine the seam between the effects of learning and the design characteristics of the brain. This area combines three different sources of information: 1) the examination of the functional architecture of language abilities, which has an evolutionary history and is well documented; 2) the neural substrate of reading, which is a relatively recent human achievement, and is parasitic upon language abilities; and 3) well-defined differences between the structure of languages in general, and in the manner in which they represent spoken language in their orthography in particular.

The present experiments are part of a research plan that takes advantage of some principled differences between Hebrew, Arabic, and English, to explore a componential analysis of the reading process in different languages, and the effects of different components (visual, orthographic, and morphological demands) on the hemispheric division of labor in reading. The three languages utilize alphabetic orthographies, but differ in interesting ways: in reading direction, orthographic complexity, and morphological structure. In the present study we examine the effects of these differences on the involvement of the two cerebral hemispheres in a lateralized lexical-decision task, and focus on differences in morphological structure.

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In English, which has a concatenative morphology, multimorphemic words are usually created by affixation, where the stem is usually a word itself, and its orthographic integrity is largely preserved. Arabic and Hebrew are characterized by a nonconcatenative, highly productive derivational morphology (Berman, 1978). Most words are derived by embedding a root into a morphophonological word pattern. In both languages, most words are based on a trilateral root and various derivatives that are formed by the addition of affixes and vowels. The roots and phonological patterns are abstract entities and only their joint combination forms specific words. The core meaning is conveyed by the root, while the phonological pattern conveys word class information. For example, in Arabic the word TAKREEM consists of the root KRM, whose semantic space includes things having to do with respect, and the phonological pattern TA_ _ EE_. The combination results in the word 'honor.' In Hebrew, the word SIFRA consists of the root SFR- whose semantic space includes things having to do with counting, and the phonological pattern _I_ _A, which tends to occur in words denoting singular feminine nouns, resulting in the word 'numeral.' The letters that make up the root may be dispersed across the word, interdigitated with letters that can double as vowels and other consonants that belong to the morphological pattern.

A number of psycholinguistic studies (Frost & Bentin, 1992; Feldman, Frost, & Pnini, 1995; Frost, Forster, & Deutsch, 1997; Deutsch, Frost, & Forster, 1998; Berent, 2002) have explored the effects of the morphology and orthography of Hebrew on lexical access and the structure of the mental lexicon. These authors have suggested that the nonconcatenative and agglutinative morphological structure of Hebrew, together with the distributional properties of abstract word forms, results in the inclusion of subword morphological units in the mental lexicon of Hebrew speakers. In addition, morphologically complex Hebrew words cannot be read via incremental parsing (sequentially, letter by letter). This last claim converges with the conclusions of Eviatar (1999, Experiment 4), who showed that nonwords are processed sequentially in both visual fields in English, but in neither visual field in Hebrew, and hypothesized that this is because Hebrew nonwords cannot be read sequentially. Farid and Grainger (1996) suggested the same for the reading of Arabic. They showed that initial fixation position in a word results in somewhat different response patterns in French (which is similar to English in morphological structure and in reading direction) and in Arabic (which is similar to Hebrew in morphological structure and in reading direction). In French, fixation slightly to the left of the word's center results in best recognition for both prefixed and suffixed words, while in Arabic, prefixed words result in best recognition from leftward fixations and suffixed words result in best recognition from rightward initial fixations. They suggest that this is due to the greater importance of morphological structure in Arabic, because ". . .much of the phonological representation of the word can be recovered only after successfully matching the consonant cluster to a lexical representation" (Farid and Grainger, 1996, p. 364), that is, after extraction of the root. Berent (2002) has also concluded that in Hebrew, "Speakers decompose the root from the word pattern in online word identification. . ." (p. 335). Prunet, Beland, and Idrissi (2000) report a case study of an Arabic-French agrammatic patient, who showed identical deficits in the two languages, except for a specific type of error, metathesis, in which he modified the order of the root consonants, with the vowel patterns remaining intact, only in Arabic, not in French. They interpret this finding as reflecting the manner in which words are stored in the mental lexicon in the two languages: whole words plus affixes in French, and roots plus word patterns in Arabic.

Previously we have shown that lifelong reading habits (both Hebrew and Arabic are read from right to left, whereas English is read from left to right) can affect the efficiency with which skilled readers can ignore information on the side from which reading usually begins (Eviatar, 1995) and performance asymmetries in tasks thought to reflect right hemisphere (RH) dominance (such as the processing of emotions in chimeric faces [Eviatar, 1997]).

Examination of the differences in orthography/phonology relations among the languages, together with the language experience of the participants, revealed that strategies of phonological encoding that are specific to an orthography seem to be used also while reading a second language (Eviatar, 1999), and that the processing of Arabic orthography seems to make different demands on the cognitive system both in beginning (Eviatar & Ibrahim, 2004) and in skilled readers (Ibrahim, Eviatar, & Aharon-Perez, 2002). When we examined letter and syllable identification in the two cerebral hemispheres of Arabic-Hebrew bilinguals, we found patterns that suggested that the RH may have a specific difficulty with certain letters in Arabic, but not in Hebrew. We suggested that this is due to two characteristics of Arabic orthography that make it specifically harder for the RH to process than Hebrew. The first characteristic is the extensive use of dots in Arabic script: 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. Using hierarchical stimuli, we showed that the RH does not distinguish between these letters, whereas the left hemisphere (LH) does so (Eviatar, Ibrahim, & Ganayim, 2004). The second characteristic has to do with the fact that in both Hebrew and Arabic some letters are represented by different shapes, depending on their placement in the word. However, 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, and ך-כ. In Arabic, 22 of the 28 letters in the alphabet have four shapes (word initial, medial, final, and when they follow a nonconnecting letter, e.g., the phoneme /h/ is represented by the graphemes:, ـه and ه in word final position, after a connecting and a disconnecting letter respectively, ـهـ when it is in the middle of the word, and هـ when it is word initial. Six letters have two shapes each, final and separate. Thus, in Arabic, very similar graphemes represent different phonemes, while the same phoneme is represented by different graphemes. Our data suggest that these two features result in longer response times and more errors in the LVF(RH) than in the RVF(LH) (Eviatar & Ibrahim, 2004).

Most recently we reported that the different manner in which words are constructed in English and in Hebrew and Arabic has an effect on the division of labor between the cerebral hemispheres in a lateralized lexical-decision task (Eviatar & Ibrahim, 2007). We presented native speakers of Arabic, Hebrew, and English with morphologically simple and complex words and nonwords in their native language, and measured indexes of hemispheric integration. In English, we replicated the findings of previous studies: similarly to Iacoboni and Zaidel (1996), we showed that while the RH is able to independently recognize nonwords; it draws upon resources of the LH when encountering words. Similarly to Burgess and Skodis (1993) in English, and to Koenig, Wetzel, and Caramazza (1992) in French, we showed that for the English speakers, only the LH was sensitive to the morphological complexity of the stimuli. As opposed to the English speakers, both groups of speakers of the Semitic languages showed bilateral sensitivity to morphological complexity. We suggested that the nonconcatenative morphology of the Semitic languages, requiring the analysis of words into their root and word-form constituents, requires that both hemispheres be sensitive to morphological structure. Thus, the manner in which words are formed in these different languages resulted in different types of interhemispheric division of labor in the lexical-decision task. In that study, the language of the test was manipulated between groups, as each language was read by native speakers of that language. In the current study, native Arabic speakers, being trilingual, were tested in all three languages, allowing us to test the effects of language status in addition to language structure on hemispheric involvement and interhemispheric integration in the lexical-decision task. Specifically, we are interested in how the status of a language in the personal history of the individual (native vs. second or third language) together with other linguistic factors (lexicality, morphological complexity of the stimulus, and the type of orthography and morphology of the test language), influence hemispheric function.

The Neuropsychology of Multilingualism

The consensus in the field today is that language organization in multilinguals is similar in all of their languages, and is somewhat different than in monolinguals (Kovelman, Shalinsky, Berens, & Pettito, 2008). Imaging studies have generally shown that the same brain regions are activated when polyglot individuals process their various languages. The general finding is that functioning in the less proficient language results in larger extents or more intense activation measures than functioning in L1 (Abutalebi, Cappa & Perani, 2001). Highly proficient polyglots show more activation in all of their languages than monolinguals in both of their hemispheres (Kovelman et al., 2008). This finding dovetails with the concept of "conscription" of brain regions as tasks become more demanding (Just, Carpenter, Keller, Eddy & Thulborn, 1997), given the assumption that linguistic processing in multilinguals is always more demanding than in monolinguals.

The classic studies of functional organization of different languages in the brains of bilinguals were done by Ojemann and his colleagues (e.g., Ojemann & Whitaker, 1978). More recently, Lucas, McKhan, and Ojemann (2004) found common areas of the cortex involved in two languages of epileptic bilingual patients (who were candidates for surgical intervention) using stimulation mapping with a naming task. In monolinguals, it is generally found that the cortical regions involved in naming are larger in adults than in children. Overall, when compared to monolingual adults, the bilingual patients did not reveal a systematically different distribution of brain areas necessary for naming. However, when the maps of regions involved in L1 in the adult bilingual patients were compared with those of monolingual children, Lucas and his colleagues (2004) found that the regions crucial for naming in monolingual children were exclusively involved in L1 naming in the bilingual adults, supporting the hypothesis that L1 is acquired using different mechanisms than later learned languages.

The behavior of multilingual aphasics is usually consistent across their different languages, although paradoxical and intriguing patterns of differential impairments, including even alternating impairments in different languages have suggested that complex relationships between substrate and behavior (e.g., Paradis & Goldblum, 1989).

The neuropsychological view of multilingualism is based on a variety of paradigms that differ both in the characteristics of the multilinguals (brain damaged patients with aphasia, patients with epilepsy, and both early and late bilinguals with differing levels of proficiency in their languages), and in the types of linguistic tasks that they are asked to perform (speech production, listening to stories, translation, and semantic decisions). Two questions are generally asked, one having to do with the difference between the linguistic functional architecture of polyglots versus monolinguals, and the second having to so with the relative organization of several languages in the same brain. Our study examines the latter question, and focuses on the early stages of reading. As detailed below, our population of Israeli Arabs is a uniquely complicated case of multilingual literacy, and allows us to examine the interaction of language status and orthographic and lexical processing.

The Complicated Case of Multilingualism in Arabic

In Arabic, the spoken form (*ammia*—the local dialect) is used by speakers of the language in a specified geographic area for daily verbal communication, and is the native language of virtually all Arabic speakers. This form is differentiated from the *fus[udot]s[u-dot]ha* (the literary form), which is the language in which all speakers of Arabic, from all over the world, read and write. This literary Arabic is universally used in the Arab world for formal communication and is known as "written Arabic" or "Modern Standard Arabic" (MSA). Spoken Arabic (SA) appears entirely in colloquial dialect and has no written form.

Although they share 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 MSA; in Spoken Arabic, words may begin with two consecutive consonants or with a consonant and a 'schwa,' whereas this is illegal in MSA; 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. This situation served as part of the background to the introduction of the term "diglossia" by Ferguson in 1959 (Ferguson, 1959), and has generated a long debate over the distinction between diglossia and bilingualism (e.g., Eid, 1990).

Eviatar and Ibrahim (2001) examined this question directly by asking whether the two forms of Arabic are different enough from each other to result in the pattern typical of bilingualism. To achieve this goal, Arabic-speaking children, who are exposed to both Spoken Arabic (SA) and LA, were compared to Russian-Hebrew bilinguals and Hebrew-speaking monolinguals on tests that focused on metalinguistic skills (the awareness of language arbitrariness and phonological awareness), and vocabulary. All of the children were in kindergarten or in first grade. The results showed the classic pattern resulting from exposure to two languages: higher performance levels in metalinguistic tests, and lower performance levels in the vocabulary measure as compared to monolinguals. The Arab children's performance levels mimicked those of the bilingual children for the most part, and suggested that exposure to Literary Arabic in early childhood affects metalinguistic skills in the same manner as that reported for children exposed to two different languages.

Thus, the linguistic requirements of literate Israeli Arabs are quite complex. Adults can minimally be considered quadri-lingual, with SA as first language (L1), and MSA, Hebrew, and English as additional languages. Because SA does not have a written form, all reading and writing are in the nonnative language. Thus, Arab children enter first grade as bilinguals, and those who attend the Arab school system begin to learn to read literary Arabic in first grade, to speak Hebrew in second grade, and to read and write in Hebrew and in English in third grade. Saiegh-Haddad (2003) has shown that the phonological distance between the two forms of Arabic is related to difficulties in reading acquisition in first grade. At the high-school level, most students are as proficient in Hebrew as they are in MSA.

Ibrahim has compared the relationships between the two forms of Arabic (SA and MSA) to the relations existing between MSA and Hebrew using semantic and repetition priming techniques (Ibrahim & Aharon-Perez, 2005; Ibrahim, 2006). Ibrahim and Aharon-Perez (2005) found similar cross-language semantic priming effects from MSA to SA and from Hebrew to SA, both about half the magnitude of the within-language (SA) priming effects. These patterns are congruent with previous reports of differences between L1 and L2 priming effects (e.g., Altarriba, 1990; Keatly, Spinks, & de Gelder, 1994). The interpretation of the difference between the patterns of semantic priming effect suggested that, at least in regard to their connections with the semantic network, MSA, as well as Hebrew, constitute second languages for the bilingual native speaker of SA.

However, Ibrahim (2006) has shown that the relations between SA as L1 and MSA and Hebrew are also somewhat different. He looked at the difference in semantic overlap of Hebrew-MSA and SA-MSA translation equivalents, and tested to see whether these cross language priming effects remained constant across lags. The results showed larger priming effects for cognate Hebrew–MSA than for SA–MSA pairs at lag 0, but the opposite pattern at lag 4. Ibrahim concluded that nonlinguistic factors qualified the influence of the linguistic factors in determining the magnitude of the morpho-phonemic similarity effects. Specifically, he proposed that among these factors are lexical-episodic associations, which are apparently stronger between translation equivalents in two languages that are interactively and concomitantly used on an everyday basis (such as SA and MSA), than between translation equivalents in languages that are not concomitantly used (such as Hebrew and LA).

The Present Study

In the present study we tested native Arabic speakers in the language they learned to read first, MSA (henceforth called Arabic), in Hebrew, a language they started learning in second grade and in which they are very proficient, and in English, which they started to learn in third grade, but do not use as much as Hebrew. In our previous studies, we showed that the RH of Arabic speakers is capable of recognizing letters in Hebrew, but not in Arabic (Eviatar & Ibrahim, 2004; Eviatar et al, 2004). In the present study we used a higher level task, lexical decision. Given that word recognition involves phonological and semantic processing, in addition to orthographic processing, we can ask how the RH of Arabic readers recognizes words in Arabic, where letter recognition is deficient, as compared with Hebrew, which is similar to Arabic in morphological structure, and in which letter recognition by the RH is not deficient. In addition, we can compare hemispheric division of labor when the test language is English, which differs from both Hebrew and Arabic in morphological structure.

In our lexical-decision task we presented letter strings in the lateralized visual fields. In the unilateral condition a single stimulus was presented either to the right or to the left of fixation on each trial. In the bilateral condition, two stimuli were presented, one in each visual field, and the target stimulus was underlined. In all of the languages, half of the stimuli were morphologically simple or complex words, and half were morphologically simple or complex nonwords. These manipulations in each language are described in detail below and in Eviatar and Ibraihim (2007). The task was to decide if the letter string is a word in the language of the test. We use three measures of hemispheric involvement: the processing dissociation, the bilateral effect, and the effects of distractor status. The logic of each index is detailed below:

The processing dissociation. This is an interaction between a stimulus variable (in our case, there are two such factors: lexicality and morphological complexity) and the visual field to which the target is presented. The interpretation of such a pattern rests on the reasoning that if the stimulus variable affects responses in one visual field and not the other, we have evidence for different and independent processes in the two hemispheres. Thus, effects of stimulus lexicality (word vs. nonword) or morphological complexity in one visual field but not the other will support the hypothesis that each stimulus is processed by the hemisphere contralateral to the stimulated visual field.

Distractor status. In the bilateral experiments the participants are presented with two stimuli on each trial, and are required to ignore one and to make a lexical decision on the other. We can examine the effects of the lexical status of the distractor (the stimulus to be ignored) on the response to the target. The logic is the following: if stimuli in one visual field are processed independently by the contralateral hemisphere, then the lexical status of the distractor presented in the other visual field (to the other hemisphere) should not affect performance. However, if one hemisphere draws upon resources of the other hemisphere to perform the task, then we will see an effect of the distractors. Analysis of the direction and degree of this effect in our experiments will clarify the conditions under which hemispheric communication occurs.

The bilateral effect. The third measure of interhemispheric integration results from comparison of the unilateral and the bilateral conditions. Boles (1990) reported that performance asymmetries are larger when stimuli are presented bilaterally (with a cue marking the side to which to respond) than when they are presented unilaterally. He proposed that this "bilateral effect" occurs because bilateral presentation of different stimuli to homologous areas of the two hemispheres disrupts communication between them. Iacoboni and Zaidel (1996) have suggested that the degree of the bilateral effect allows assessment of interhemispheric interactions for different types of stimuli. That is, processes that are performed independently by each hemisphere should not result in different performance asymmetries with unilateral or bilateral presentations, whereas processes that require interhemispheric cooperation should result in larger performance asymmetries with bilateral presentation. For example, if interhemispheric communication increases with task difficulty, and if bilateral presentation disrupts communication between the hemispheres, then we expect larger differences between unilateral and bilateral conditions in the non-native languages.

We are interested in two major questions. The first has to do with the effects of language status and structure on the division of labor between the hemispheres in the reading of single words. In our previous study examining the effects of morphological complexity on the hemispheric division of labor in the three languages (Eviatar & Ibrahim, 2007), we showed that in native readers, there are different patterns of this division of labor. We measured hemispheric cooperation as will be detailed below, and saw that in English, the LH seemed to perform independently, whereas the RH seemed to utilize LH resources; in Hebrew, the pattern of results suggested intense interhemispheric cooperation in both directions, whereas in Arabic, the patterns suggested hemispheric independence. The linguistic abilities of Arabic trilinguals allow us to ask whether these different patterns of cooperation are a result of the demands of the language of the test, or whether they reflect reading strategies that are particular to the participants. Thus we will be comparing indices of hemispheric cooperation between the language conditions.

The second major question we asked has to do with the interaction between structural differences between the languages, the status of the language in the cognitive system of the participants, and hemispheric abilities. We proposed that because morphology is central to the access of meaning in the Semitic languages, the RH of readers of these languages, as in readers of Finnish, must be sensitive to morphological structure. If that is the case, will it also be sensitive to morphological structure in a morphologically complex second language such as Hebrew and a morphologically simple second language such as English? Thus, we compared hemispheric sensitivity to morphology in the three languages.

To summarize, we tested two main sets of hypotheses. The first set focused on the involvement of the RH in reading different languages, when the first language learned was Arabic, the second Hebrew, and the third, English. This is interesting because previously we have shown that the RH has difficulty recognizing letters in Arabic, but not in Hebrew, in this population of native Arabic speakers. The second set of hypotheses focused on interhemispheric interaction while these trilinguals performed a lexical-decision task in Arabic and Hebrew, which are similar in the type of complex morphology, versus, in English, in which morphological complexity is defined differently. This allows us to examine both the effects of morphology and the effects of language status on hemispheric processing.

Method

Participants. The participants were 37 native Arabic-speaking students at Haifa University All were right-handed, neurologically healthy, and had normal or corrected-to-normal vision. All of the participants began learning to read Arabic in first grade, Hebrew in second grade, and English in third grade. Nineteen participants completed the bilateral presentation paradigm, and 18 completed the unilateral presentation paradigm.

Stimuli. We compiled three lists of 80 words and 80 nonwords, one in each language. These are listed in the Appendix. All of the words in all of the lists were nouns. Of the words, 40 were morphologically simple and 40 were morphologically complex. In Hebrew and Arabic, morphological complexity was operationalized as the transparency of the root, such that words derived from generative roots were considered complex, and words in which the roots are not generative (they appear only in that form) were considered simple.[1] In English morphologically complex words were derivations. The lists were equated on the average frequency of the nouns, and for the number of letters in the words and orthographic redundancy (i.e., the number of "neighbors," defined as the value *N* representing the number of different words that can be formed by changing only one letter in each stimulus).

Nonwords were also morphologically manipulated. Morphologically simple nonwords in English were derived from the simple words by changing one or two letters, and complex nonwords were legal but unfamiliar combinations of real morphemes (e.g., gapty). In Hebrew and in Arabic, morphologically simple nonwords were created in the same manner as in English, by changing one or two of the letters of the real words. Morphologically complex nonwords were created by embedding nonexistent "roots" into real word forms. Recall that in both Semitic languages, many words are formed by the interdigitation of root letters into paradigmatic wordforms (*binyanim* for verbs and *mishkalim* for nouns—our word stimuli were all nouns, so we used noun word forms as the basis for the morphologically complex nonwords). Thus nonwords in both English and the Semitic languages were phonologically and orthographically legal, but had no meaning.

All of the stimuli were either five or six letters long. The English stimuli were presented in Times New Roman font, the Hebrew stimuli in Guttman-Miryam font, and the Arabic stimuli in MSC Madinah S U Normal font. All were in font size 22, resulting in the longest words subtending 2.5° of visual angle. All words appeared as white letters on a gray screen. Within each language words and nonwords were presented in pseudorandom order such that they did not appear more than three times consecutively in a visual field. Each participant saw 40 items in each visual field, 20 words and 20 nonwords. Of these, 10 were morphologically simple and 10 were morphologically complex. In the bilateral condition, each morphological and lexical target was paired with a morphologically and lexically same or different distractor.

Procedure. The participants were tested in Arabic Hebrew and English in separate sessions, with 1–3 weeks between tests. The participants were tested individually. The stimuli were presented on a Silicon Graphics Workstation. On each trial the sequence of events was the following: a 1000-Hz tone sounded for 100 milliseconds (ms) to alert the participant that the trial was beginning. Then the fixation cross was presented for 100 ms. The stimuli were presented for 180 ms horizontally, with their inner edge 2° of visual angle offset from fixation. In the unilateral condition the stimuli appeared either in the left or the right visual field. In the bilateral condition two stimuli were presented on each trial, one in each visual field. One stimulus was underlined, indicating that it was the target and that the other stimulus should be ignored. The stimuli were followed by a pattern-mask that remained on screen until the participant responded or 3 sec had passed. The screen was blank for 2 sec, and the next trial began. Participants responded on the keyboard by pressing the "up arrow" key if the stimulus was a real word and the "down arrow" if it was not.

Results

The correlations between median reaction time (RT) and % error were computed to test for speed–accuracy trade-offs. No speed–accuracy trade-off found in either presentation condition (all correlations smaller than 0.1).

Hemispheric Specialization for Native Versus Non-Native Languages

In order to examine hemispheric specialization for the lexical-decision task in the three languages we calculated the sensitivity measure, d'. The sensitivity measure d' is the difference between the z-scores for the probability of hits (for words) and for false alarms (FA, for nonwords), and the criterion or bias is $c = -.05(z[p(hits)]+z(p[FA])$. When the bias measure is negative, there is a bias to respond "word" and when the bias measure is positive there is a bias to respond "nonword." We used correction computations for probability values of 1 (was changed to 1–1/[2N] and 0 (was changed to 1/[2N]) based on the suggestions of Macmillan and Creelman (1991). These data are illustrated in Figure 1.

[1] This is based on the finding of Feldman et al. (1995) that skilled Hebrew readers can detach a word form more quickly from a generative root than from a nongenerative root. That is, they can divide the word into its root and word-form morphemes more easily when the root generative than when it is not.

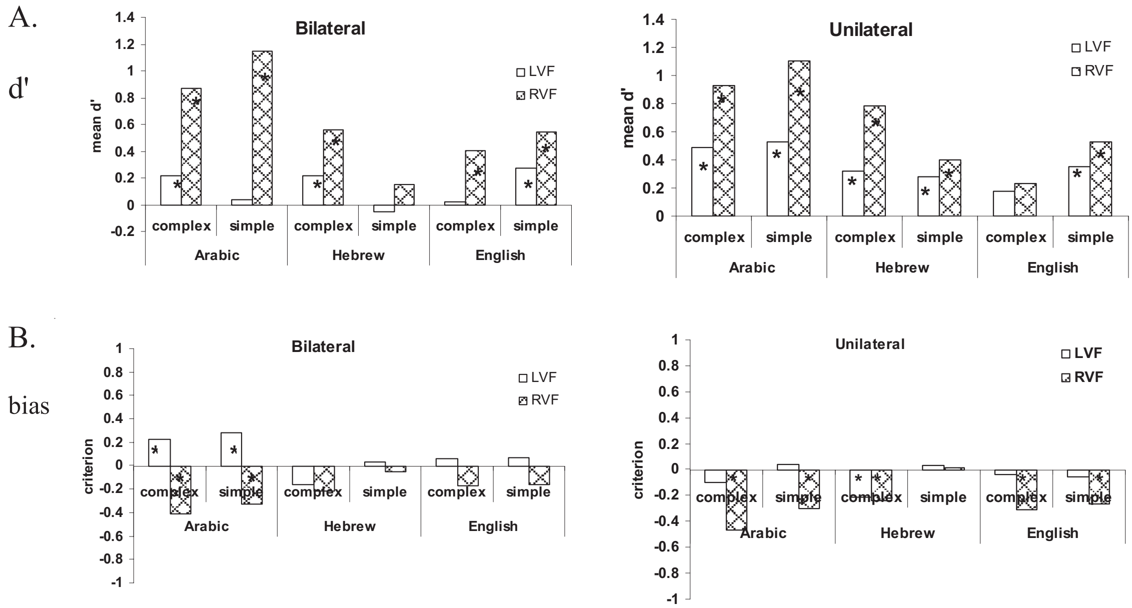

Figure 1. A: The sensitivity measure d', in the left and right visual fields in the three languages. B: Bias measures (when the bias measure is negative, there is a bias to respond "word," when the bias measure is positive, there is a bias to respond "nonword."

Sensitivity Scores: Starred bars in the two top panels of Figure 1 indicate that d' in that condition is significantly different from 0, indicating better than chance sensitivity to the lexical status of the stimuli. An ANOVA using presentation mode (unilateral vs. bilateral) as a between-groups factor and test language, visual field, and morphological complexity as within-subjects factors, revealed a significant, although small three-way interaction in the d' scores, $F(2, 70) = 3.77$, $p < .05$, $\eta_p^2 = .10$. This interaction is discussed below. Test language had a significant main effect, $F(2, 70) = 13.09$, $p < .0001$, $\eta_p^2 = .27$, and interacted with visual field, $F(2, 70) = 6.42$, $\eta_p^2 = .16$, and morphological complexity, $F(2, 70) = 16.16$, $p < .001$, $\eta_p^2 = .32$. In addition, the main effect of visual field was significant, $F(1, 35) = 24.74$, $p < .001$, $\eta_p^2 = .41$. It can be seen that d' was higher in the RVF than in the LVF in all of the conditions, reflecting the advantage of the LH in this linguistic task. The interaction between test language and visual field can be seen, where test language affected sensitivity significantly in the RVF, bilateral: $F(2, 36) = 8.3$, $p < .005$ $\eta_p^2 = .33$; unilateral: $F(2, 36) = 8.55$, $p < .001$, $\eta_p^2 = .32$; and not in the LVF (both $\eta_p^2 < .08$). The significance and size of these effects in each condition are shown in Table 1. It can be seen that all of the significant differences and comparisons in which the effect size is larger than 10%, are in the RVF. Thus, in the RVF, performance was significantly better in the native than in the nonnative languages, while in the LVF it was not. These data converge with our previous reports that there may be a specific RH deficit in the reading of Arabic (Eviatar et al., 2004).

Response Bias: Starred bars in the bottom two panels of Figure 1 indicate that the criterion was significantly different from 0. A negative score indicates a preponderance of FA, reflecting a bias to respond "word" to nonwords, while a positive score indicates a bias to respond "nonword" to words. The analysis of the criterion scores revealed an interaction between test language and visual field, $F(2, 70) = 11.3$, $p < .0001$, $\eta_p^2 = .24$, and between test language and morphological complexity, $F(2, 70) = 9.46$, $p < .0001$, $\eta_p^2 = .21$. These are examined more closely below. There were significant main effects of visual field, $F(1, 35) = 18.34$, $p < .0001$, $\eta_p^2 = .34$, and of morphological complexity, $F(1, 35) = 25.89$, $p < .0001$, $\eta_p^2 = .42$. It can be seen in Figure 1 that the main effect of visual field is due to an overall tendency toward unbiased responses in the LVF (0.01) and a stronger bias to respond "word" in the RVF (−0.24). The main effect of morphology is due to a stronger bias toward "word" responses for complex stimuli (−0.17) than for simple stimuli (−0.06). We return to these patterns below.

Morphological Complexity

Given that morphological complexity was defined differently in the Semitic languages and in English, we examined the patterns of sensitivity and bias in the three language conditions separately.

Sensitivity scores. In the sensitivity measure, the main effect of visual field was significant in the three languages, but the effect is largest in Arabic, $F(1, 35) = 23.87$, $p < .0001$, $\eta_p^2 = .41$; Hebrew = $F(1, 35) = 6.86$, $p < .01$, $\eta_p^2 = .16$; English = $F(1, 35) = 6.35$, $p < .05$, $\eta_p^2 = .15$. The main effect of morphological complexity was significant only in the nonnative languages, English = $F(1, 35) = 12.86$, $p < .01$, $\eta_p^2 = .27$; Hebrew = $F(1, 35) = 26.59$, $p < .0001$, $\eta_p^2 = .43$, but in opposite directions. In English, d' was significantly higher for morphologically simple stimuli than for complex stimuli, whereas in Hebrew sensitivity for complex stimuli was higher than for simple stimuli. These patterns are similar to the ones reported for native speakers of English and Hebrew (Eviatar & Ibrahim, 2007). Most interestingly, morpho-

Table 1
Significance and Size of the Effects of Test Language in Sensitivity Scores (d′) in Each of the Experimental Conditions

Visual field morphology	Bilateral presentation (df = 1,34)				Unilateral presentation (df = 1, 36)			
	LVF		RVF		LVF		RVF	
	Complex	Simple	Complex	Simple	Complex	Simple	Complex	Simple
Arabic vs English	ns, $p < .14$, $\eta_p^2 = .06$	ns, $p < .17$, $\eta_p^2 = .05$	$F = 5.4$, $p^* < .02$, $\eta_p^2 = .14$	$F = 9.10$, $p^* < .005$, $\eta_p^2 = .21$	ns, $p > .08$, $\eta_p^2 = .08$	ns, $p > .2$, $\eta_p^2 = .04$	$F = 16.66$, $p^* < .001$, $\eta_p^2 = .32$	$F = 8.60$, $p^* < .01$, $\eta_p^2 = .19$
Arabic vs Hebrew	ns, $p > .9$, $\eta_p^2 = .00$	ns, $p < .5$, $\eta_p^2 = .00$	ns, $p > .13$, $\eta_p^2 = .06$	$F = 24.18$, $p^* < .0001$, $\eta_p^2 = .42$	ns, $p > .34$, $\eta_p^2 = .02$	ns, $p > .08$, $\eta_p^2 = .08$	ns, $p > .41$, $\eta_p^2 = .02$	$F = 12.9$, $p^* < .001$, $\eta_p^2 = .26$
English vs Hebrew	ns, $p < .13$, $\eta_p^2 = .06$	$F = 3.89$, $p = .057$, $\eta_p^2 = .10$	ns, $p > 4$, $\eta_p^2 = .02$	$F = 3.61$, $p = .066$, $\eta_p^2 = .03$	ns, $p > .43$, $\eta_p^2 = .02$	ns, $p > .64$, $\eta_p^2 = .00$	$F = 10.56$, $p^* < .002$, $\eta_p^2 = .23$	na, $p > .5$, $\eta_p^2 = .00$

* Significant difference between the languages.

logical complexity interacted with visual field in Arabic, $F(1, 35) = 4.10$, $p = .05$, $\eta_p^2 = .11$. Perusal of Figure 1 reveals that this small effect is due to chance performance in the bilateral experiment in the LVF with morphologically simple stimuli, and better than chance performance in the LVF in all the other conditions. In the RVF, all of the d' scores were significantly better than chance.

Response bias. Tests on our measure of response bias revealed a significant effect of morphological complexity in the Semitic languages, Arabic, $F(1, 35) = 9.16$, $p < .01$, $\eta_p^2 = .21$; Hebrew, $F(1, 35) = 42.47$, $p < .0001$, $\eta_p^2 = .55$, such that there was a strong bias to respond "word" for complex stimuli but not for simple stimuli. Recall that complex nonwords were comprised of nonexistent roots embedded in real word forms. This resulted in many nonwords of this type being erroneously categorized as words (more false alarms). In Hebrew this occurs in both visual fields (see Figure 1), suggesting that both hemispheres were sensitive to the difference between simple and complex stimuli. Although the morphologically complex nonwords in English were created from the illegal combination of real morphemes (e.g., legly), this did not result in larger biases than the morphologically simple nonwords. In both English and in Arabic, responses in the RVF to both types of stimuli resulted in biases to respond "word," Arabic, $F(1, 35) = 35.30$, $p < .0001$, $\eta_p^2 = .50$; English, $F(1, 35) = 7.92$, $p < .05$, $\eta_p^2 = .18$. It can be seen that in the bilateral condition, in the LVF, Arabic stimuli resulted in the opposite bias, a tendency to respond "no" to real words, both complex and simple. It is not clear why Arabic and English pattern together in this manner, and are different form Hebrew. One clue may be that as described below, the interhemispheric data (specifically the effects of distracter status) suggest that in Hebrew, words presented to the LVF (RH) were processed with the aid of the LH, and thus we see a reflection of its sensitivity to morphological structure in both visual fields. It may be that in Arabic and in English we are seeing hemispheric differences in bias because we are seeing independent hemispheric processing.

Interhemispehric Interactions

We used three indices to examine hemispheric interactions in each language. We used median reaction times to correct responses and percent errors as dependent measures, to allow us to examine interactions with the lexicality of the stimulus (sensitivity measures include lexicality, such that different patterns between words and nonwords cannot be discerned).

The processing dissociation. Recall that this index is a significant interaction between a stimulus variable and visual field of presentation. In Figure 2, the response patterns of both groups to complex and simple words and nonwords are illustrated. The significance and size of the relevant statistical effects are listed in Table 2. Significant simple effects are indicated as stars in Figure 2.

It can be seen that both groups reveal a processing dissociation suggesting independent hemispheric processing of words and nonwords in all three languages. There is a general right visual field advantage (RVFA) for words and a small left visual field advantage (LVFA) or no advantage for nonwords. These patterns are not modulated by the morphological complexity of the stimuli, as the three-way interaction between lexicality, morphology, and visual field was not significant in any of the

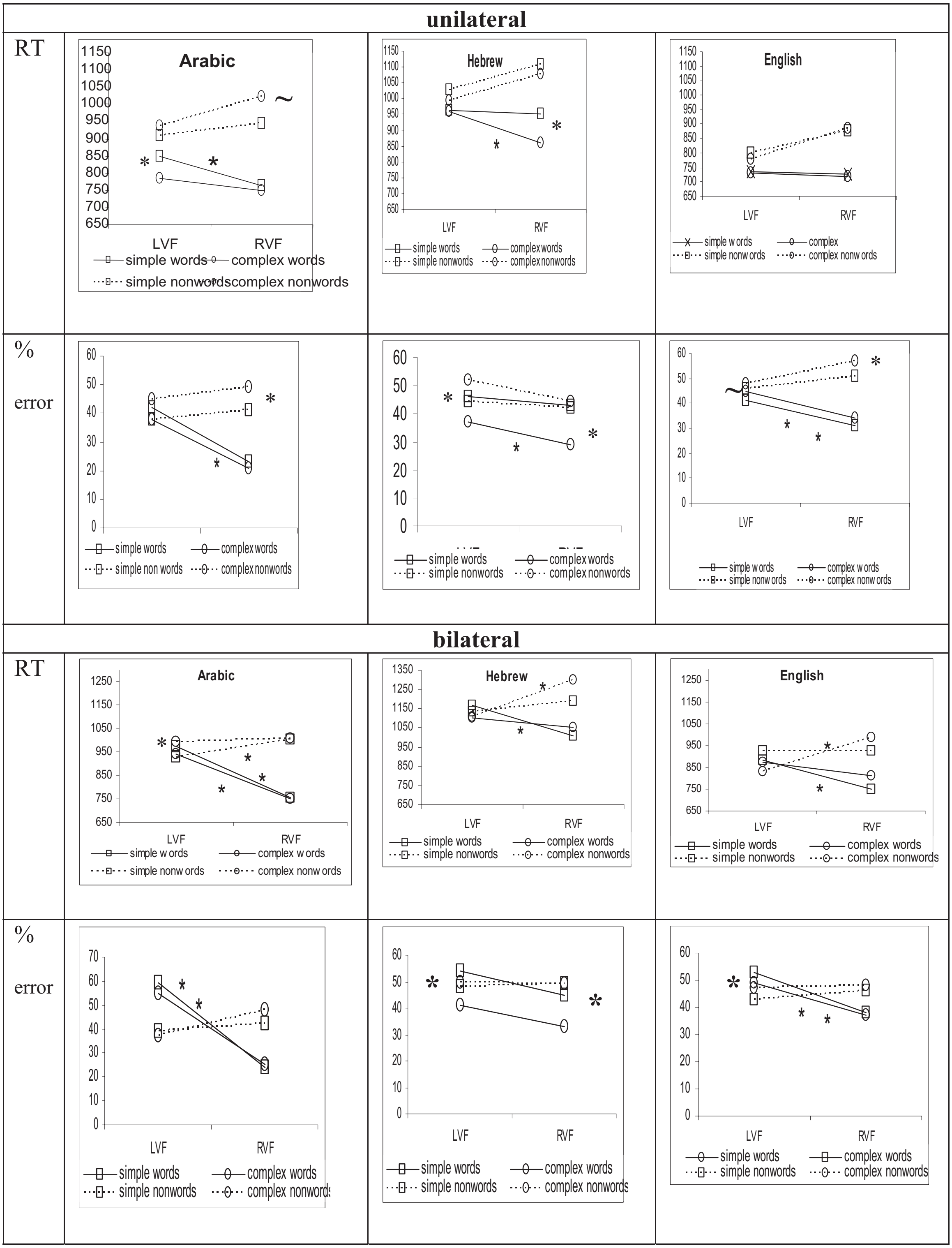

Figure 2. Effects of lexicality, morphology, and visual field in each language $^{*}p < .05$, $\sim p < .09$.

Table 2
The Processing Dissociation: Significance and Size of Effects for Lexicality, Morphological Complexity, and Visual Field in Each Presentation Condition

	Arabic		Hebrew		English	
	Unilateral	Bilateral	Unilateral	Bilateral	Unilateral	Bilateral
A. MedRT						
Lexicality × visual field	F = 3.97, p = .06 η^2_p = .18	F = 8.41, p < .01, η^2_p = .33	F = 8.44, p < .01 η^2_p = .32	F = 7.15, p < .05 η^2_p = .30	F = 4.19, p = .055 η^2_p = .19	F = 8.7, p < .01 η^2_p = .34
Morphology × visual field	Ns, η^2_p = .06	Ns, η^2_p = .008	Ns, η^2_p = .05	F = 9.84, p < .01, η^2_p = .37	Ns, η^2_p = .01	F = 6.72, p < .01., η^2_p = .28
B. % Errors						
Lexicality × visual field	F = 16.90, p = .001, η^2_p = .48	F = 18.01, p < .01,η^2_p = .51	ns, η^2_p = .0	ns, η^2_p = .0	F = 6.77, p = .05, η^2_p = .27	Ns, η^2_p = .15
Morphology × visual field	ns, η^2_p = .0	F = 3.42, p = .08,η^2_p = .17	ns, η^2_p = .09	ns, η^2_p = .0	ns,η^2_p = .0	ns, η^2_p = .0

Note. Df in the unilateral condition = 1,18; in the bilateral condition = 1,17.

language and presentation conditions. The interaction of morphological complexity with visual field of presentation in response times was significant only in the most difficult conditions: when the stimuli were in a nonnative language, and only in the bilateral condition. This may reflect a hemispheric division of labor in response to task difficulty, as suggested by Banich (e.g., Banich, 1995).

Thus the processing dissociation measure suggests independent hemispheric processing for words and nonwords, with a general advantage for words in the RVF (LH), and hemispheric equivalence or a small advantage in the LVF (RH) for nonwords. These patterns hold for all the language conditions, and are similar to the canonical lexicality by visual field interaction found in many studies in English.

The bilateral effect. Recall that the logic underlying this measure is based on the hypothesis that bilateral presentation of stimuli to homologous regions of the two hemispheres disrupts communication between them. Thus, if interhemispheric integration occurred in the unilateral paradigm, it will be disrupted in the bilateral paradigm. Operationally, this hypothesis predicts that the performance asymmetry will be larger in the bilateral than in the unilateral presentation conditions. In order to test this, we created an asymmetry measure (LVF-RVF), and tested to see if it was different in the bilateral and unilateral conditions, for words and nonwords and for simple and complex stimuli. We used a three-way ANOVA with Presentation mode (unilateral vs. bilateral) as a between groups factor and language, lexicality, and morphology as within-subject factors. We are interested in the conditions in which the performance asymmetry differs significantly in the bilateral and unilateral conditions. In errors no effects were significant. In response times, Presentation mode had a marginally significant main effect, $F(1, 35) = 3.61$, $p = .06$, $\eta^2_p = .09$, but most importantly, interacted significantly with test language and morphological complexity, $F(2, 70) = 3.94$, $p < .05$, $\eta^2_p = .10$. This interaction is illustrated in Figure 3. The interaction between presentation mode and morphological complexity was also significant, $F(1, 35) = 4.13$, $p < .05$, $\eta^2_p = .11$. Table 3 presents the mean response time differences between the left and right visual fields in all of the conditions, and the result of comparing them, the simple main effect of presentation mode.

It can be seen that the pattern is slightly different in the three languages. In Arabic, there is a bilateral effect for words, but not for nonwords, whereas in the nonnative languages there is again, no bilateral effect for nonwords, but a significant effect for simple words. In terms of an index for hemispheric integration, for words but not for nonwords, this index is consistent with the processing dissociation index. The results suggest that nonwords are identified by each hemisphere independently, while hemispheric cooperation is necessary when the stimuli are words. These results are similar to those reported by Iacoboni and Zaidel (1996) and Eviatar and Ibrahim (2007) for English speakers reading English.

Distracter status. In the third index we measured the effects of the distractor in the bilateral condition. The idea is that if there is hemispheric independence, then the type of distractor displayed in the other VF shouldn't affect responses. But, if there is hemispheric integration, then the congruity of the distractor and the target may affect responses. Because participants made many errors in this difficult task, and because the number of items in each cell (visual field × morphological complexity by lexicality by distracter status [same as the target or different from the target]) was not large, response times are not informative, so we computed this measure with signal detection measures only. The sensitivity data are illustrated in Figure 4.

Comparing d' and bias in the conditions in which the distractor was the same lexical category as the target resulted in two significant results in d', both in the LVF, and both when the participants were doing the test in Hebrew: for complex stimuli, F(1,

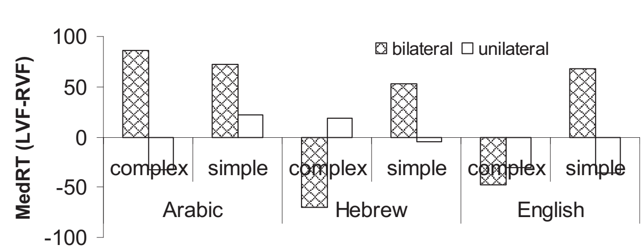

Figure 3. The bilateral effect in the three languages. Larger effects in the bilateral than in the unilateral condition imply interhemispheric interaction.

Table 3
Effects of Presentation Mode (Unilateral or Bilateral) for Morphologically Simple and Complex Words and Nonwords in Arabic, Hebrew, and English

	Arabic		English		Hebrew	
df = 1,35	Nonwords	Words	Nonwords	Words	Nonwords	Words
Complex	ns B = −22 U = −81	4.72, $p < .05$, $\eta_p^2 = .12$ B = 214 U = 33	ns B = −169 U = −104	ns B = 63 U = 13	ns B = −197 U = −82	ns B = 52 U = 99
Simple	ns B = −78 U = −38	3.37, $p = .07$, $\eta_p^2 = .09$ B = 229 U = 87	ns B = 4 U = −79	5.59, $p < .05$ $\eta_p^2 = .14$ B = 140 U = 12	ns B = −50 U = −79	ns, $F > 2$, $p = .10$ $\eta_p^2 = .07$ B = 162 U = 11

Note. The means (in Ms) that were compared are listed in each cell. B = bilateral presentation; U = unilateral presentation.

17) = 5.23, $p < .05$, and for simple stimuli, $F(1, 17) = 4.87$, $p < .05$. In both conditions, d' was higher and significantly different from chance, when the distractor was the same as the target (complex = 0.45, simple = 0.21), but not when it was different from the target (complex = −.03, simple = −.27). Thus, this measure suggests that when the participants were doing the task in Hebrew, stimuli presented to the LVF were processed with the help of resources from the LH.

Perusal of Figure 4 reveals that when the data are stratified by distractors, in the LVF/RH, sensitivity is not better than chance in Arabic, but does reach significance in Hebrew and in English, in different conditions: in the morphologically simple stimuli in English, and in the complex stimuli in Hebrew.

Discussion

The results can be summarized thus: The sensitivity measures reveal that there is LH specialization for this language task in all of the conditions. In addition, these findings support our hypothesis that there is a specific RH deficit in reading Arabic, because that is the only condition (with bilateral presentation), where these native Arabic speakers responded at chance. Our results support hemispheric independence for nonwords and hemispheric interdependence for words in all of the languages. That is, in all of the languages, the RH was able to reject nonwords independently of the LH. The pattern for nonwords was consistent in our three indexes of hemispheric relations. For words, all three indexes suggested interhemispheric interactions when the participants were doing the task in Hebrew, and two out of the three were consistent with this hypothesis for Arabic and English.

The findings reveal a pattern of similarities and differences in the processing of English, Hebrew, and MSA by native speakers of Arabic. As mentioned in the introduction, there are three major sources for these patterns. The first is the general design characteristics of the brain—the patterns is such because that is the way a human brain works, irrespective of the language of the test or its status in the history of the participants (e.g., whether it is a first or second language). The second source of performance asymmetries are the specific demands made by a particular language, with a particular orthography, on the division and type of labor in the cerebral hemispheres. The third source of variation is the language experience of the participants with the particular language used in each of the tests. Our results reveal effects of all three sources:

General effects. The general right visual field advantage that we see for words in all of our conditions probably results from LH dominance for this linguistic task, which is generalizable over languages and language status. In addition, all the participants show an effect of lexicality, and even more importantly, the canonical lexicality by visual field interaction is found in all of the conditions. This suggests that in all of the languages, the RH participated in the task.

Effects of language experience. Previously we reported that when participants are tested in their native language, English speakers reveal an effect of morphological complexity only in the RVF, whereas Hebrew and Arabic speakers show sensitivity to morphological complexity in both visual fields (Eviatar & Ibrahim, 2007). We interpreted these patterns as indicating that for English readers, only the LH is sensitive to morphology, whereas for readers of the Semitic languages, both hemispheres are sensitive to morphological structure. We suggested that this is a result of the nonconcatenative root plus word form morphology in these languages, such that if there is RH involvement in reading, it must also be sensitive to morphological structure. As shown in Figure 2, our native Arabic speakers revealed sensitivity to morphological complexity in their second languages as well. In Hebrew, this pattern is similar to native Hebrew readers. In English, this pattern is different from that shown by native English speakers, and reveals the influence of reading a second language with the same mechanisms as the first learned language. This type of pattern was also reported by Eviatar (1999) for native Hebrew readers recognizing nonsense syllables in English. Eviatar (1999) suggested that this is due to the demand for morphological decomposition in Hebrew that determines reading strategies for other languages as well.

Language-specific effects. The lowered sensitivity scores in the more difficult bilateral task in the LVF in Arabic but not in the other languages may reflect a specific difficulty of the RH with Arabic but not Hebrew or English orthography.

In summary, there are two major conclusions that can be drawn from our experiments. The first has to do with the pattern in L1

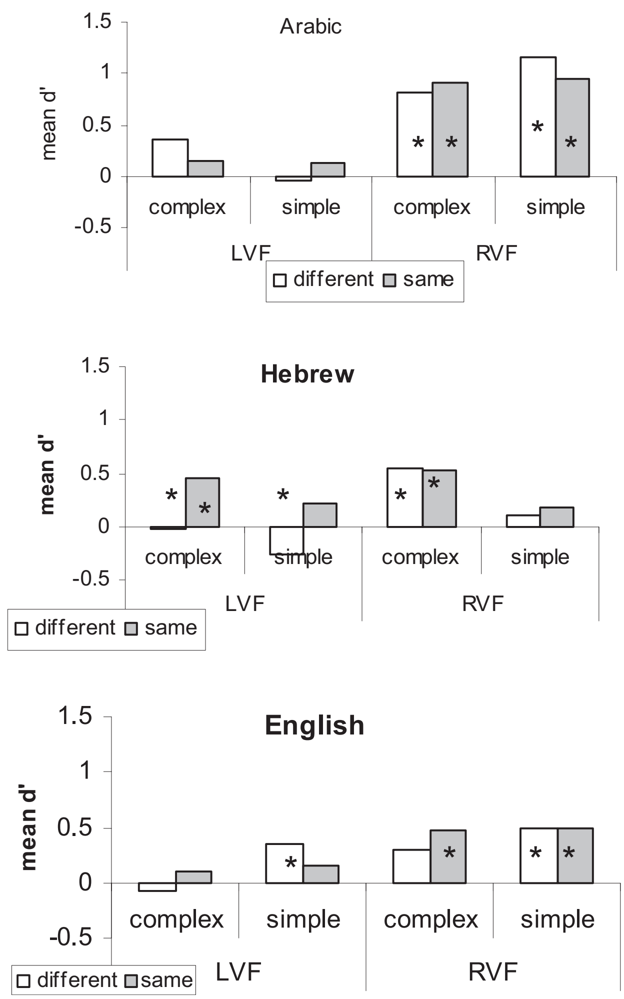

Figure 4. Effects of distractor status on sensitivity scores in the three languages. Stars inside a bar indicate that performance is better than chance, while stars between bars indicate significant differences between conditions in which the distractor is the same or different from the target in lexical status.

versus the non-native languages: sensitivity to the lexical status of the stimuli is significantly better for L1 than the other languages in the RVF/LH, but not in the LVF/RH. This finding converges with our previous reports of specific RH disability for Arabic, but not for Hebrew or English. Thus, although sensitivity was higher in the RVF than in the LVF for all of the languages, it is only in the RVF that we see the effect of language status in the history of the individual. We believe that this is due to the specific difficulty of the RH with Arabic orthography, such that performance in languages in which the participant is less proficient, but have an easier orthography, is as good as performance in their native Arabic.

The second conclusion has to do with hemispheric integration. In general, the three indexes are quite similar across the three languages: We see a visual field by lexicality interaction in all of the conditions, implying a processing dissociation that may reflect hemispheric independence in the three languages. Use of the bilateral effect suggests that in all of the languages, participants processed nonwords independently in both hemispheres, while for all words in Arabic (L1), and for morphologically simple words in English and Hebrew (the L2s), interhemispheric integrations took place. The final index, distractor status, suggested that the LH of the participants was performing the task independently in all of the languages. The data suggest that when the participants were doing the task in Hebrew, the RH utilized LH resources to make the distinction between words and nonwords. As mentioned above, this may be reflected in the patterns of bias, which were the same in the two visual fields in Hebrew, but different in Arabic and in English.

In sum, these findings reveal the dynamic properties of the hemispheric relations, reflecting the flexibility of the system when it has to deal with different types of stimuli. The morphological structures of the Semitic languages make it necessary of the RH to be sensitive to morphology (either on its own or by "using" LH facilities via interhemispheric channels). This pattern in discernable in Hebrew, which the RH can read, but not in Arabic, in which it has a specific difficulty, or in English, which does not require morphological decomposition.

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(*Appendixes follow*)

Appendix

The Stimuli

Table A1. *English*

Five-letter complex words		Six-letter complex words		Five-letter complex nonwords	Six-letter complex nonwords	
actor 24	unwed 12	singer 10	unfair 13	reday	maltor	sinder
artist 57	input 20	dancer 31	recall 39	reton	arting	sapred
owner 33		driver 49	search 66	sunly	dogist	urning
madly 4(39)		farmer 23	insane 13	fitry	ballic	pulter
sadly 12(35)		golden 42	inside 174	baral	hornal	vister
lover 19		Living 195	upward 27	armen	hatage	imseen
lucky 21		ending 31	refund 22	gapty	inbear	windly
usage 14		safety 47	reform 30	inspy	intame	wepter
voter 4		leader 74	poster 4	poomy	inchor	dinter
		worker 30	prayer 28	landy	lampen	eggely
		wooden 50		vater	litful	pilker
		bakery				
		2(36)			liping	
		beaten 15			reelope	
		hatred 20			soupen	
		ironic 13			unwasp	
		useful 58			unraim	
		verbal 21			seaper	
		saying 113			operer	
		heroic 21				
	mn freq = 37.02					
Five-letter simple words		**Six-letter simple words**		**Five-letter simple nonwords**	**Six-letter simple nonwords**	
ocean 34		engine 50	league 69	abent	ufgine	farble
agent 44		violin 11	utopia 24	doyak	gealth	benslo
dress 67		virgin 35	potato 15	amale	wanget	donkle
radio 120		motive 22	poodle 2	smage	dittle	adeast
idiot 2		battle 87	domain 9	leard	udoryp	iglipe
apple 9		advice 52	dollar 46	avort	hamage	lainth
lemon 18		wealth 22	accent 9	bemin	umtado	likcen
saint 16		heaven 43	genius 23	icrog	ansoct	rupait
beard 26		rabbit 11	sponge 7	oplep	liolin	
mouse 10		legend 26		idace	leerus	
		window				
image 119		119		ukint	wottle	
laugh 28		smooth 42		iless	sichin	
issue 152		scream 13		mooth	serble	
razor 15		screen 48			sabbit	
		forest 66			rafoon	
		lesson 29			bareom	
		pirate 4			desius	
					edoice	
	mn freq = 38.6				modolt	

Table B1. *Hebrew*

Five-letter complex words		Six-letter complex words	Five-letter complex nonwords		Six-letter complex nonwords
אבדון	לטיפה	ביטחון	אגלון	מגובק	אדיגות
אמנות	מבחנה	גמישות	בשולה	נגמקת	בוככות
בדיקה	מדריך	דלילות	בוגלת	עגורה	גשילות
בולשת	מקלט	כפילות	גשונה	פשיזה	דשישות
גבורה	נבחרת	סוכריה	גשנות	כשלדן	זימחון
גדלות	נוסחה	כוננית	דומלן	גומהב	חגלנות
דוקרן	עניבה		דנשור	מגובק	כוממית
דחפור	עבודה		חמשות	נגמקת	פמיגות
זיכרון	פציעה		חרנון	עגורה	סמלנות
חגורה	פתרון		ימידה	פשיזה	
חגיגה	פסיקה		ישגות		
חשבון	ספנות		ידולה		
ידיעה	דרכון		ישולת		
ילדות	בכורה		כשידה		
ירושה	אפודה		לביגה		
יכולת			לושבה		
כניסה			לכיחה		
לגימה			משליק		
לחישה			מקלמה		
Five-letter simple words		**Six-letter simple words**	**Five-letter simple nonwords**		**Six-letter simple nonwords**
אבטיח	פרעוש	בולדוג	אגיזר	פושלץ	בוגמון
אביון	פסנתר	בומרנג	אגומל	פולדק	נגבומל
בנזין	כולרה	גיהנום	בגליק	סמורט	גודינה
גבעול	אגרטל	דיסקית	גינרה	כומקה	גימיון
גלריה		דוכיפת	דיומן	אמרשל	דימגנג
דיוקן		חנווני	דימון		חדמוני
זעטוט		ליגיון	זרשוב		לימיון
חבצלת		לוליין	חמילה		נושמלי
חלמון		מנגנון	חורגף		פומדיה
ירבוע		מוקיון	ואריד		סגודית
יהלום		נודניק	ירעור		ביניון
יסעור		ניילון	ירדגי		דמולון
ישראל		פלסטיק	ירבעל		
כוורת		סטודנט	כומרה		
כרטיס		סמרטוט	כידרת		
לולאה		ביריון	למוגה		
מלאכה		דיונון	למיתן		
עכביש			מאולה		
עזאזל			מדזין		

(*Appendixes continue*)

Table C1. *Arabic*

Five-letter complex words		Six -letter complex words	Five-letter complex nonwords	Six -letter complex nonwords
مزرعة	مكتبة	شمعدان	مدرعة	شكعدان
محراث	صناعة	اسطوره	مكراث	اشحوره
تصعيد	مرتبة	استمرار	دناعة	استهران
مجاري	مدرسة	تعليمي	مهاري	اغتران
مقبرة	مفتاح	امتحان	مخدسة	الكتماح
تعبير	اخراج	اجتماع	مقطرة	استعراد
معركة	مكسور	استعداد	ملتاح	ازتبار
موقدة	تنظيم	اختبار	مزكبة	مرافحة
خزانة	طيارة	مكافحة	اخباج	تعليفي
مرشده	محرقة		تعنير	
مسطرة	منتوج		رافنة	
ترحيب	تحصيل		موقشة	
اخبار	مشترك		خزانة	
محلقة			محشدة	
تفكير			محبقة	
متجمد			تنخيب	
مفهوم			احباز	

Five-letter simple words		Six -letter simple words	Five-letter simple nonwords		Six-letter simple nonwords
عائلة	مروحة	سكرتير	بائلة	تفالة	سكرفتير
خنزير	جزدان	رباعكه	كنزير	مصطحة	كرسباء
زرافة	امعاء	خياشيم	كرافة	كرعول	بياريم
كركدن	صنارة	تيلفون	طنازة	كرنيت	تيلبوع
قنطار		نموذج	هصبور		سموذج
عصفور		زعفران	كعيسة		زعكراج
كنيسة		بهلوان	زابية		طهبوان
عامود		مهرجان	بسلون		مرموان
طاولة		ارجوان	كنبار		اركوان
ازةيو			بناره		
قنينة			مزوشة		
تلفاز			امعال		
بيارة			برماز		
حقيبة			مصبلة		

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