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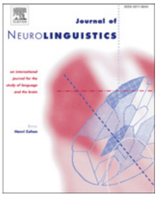

Hemispheric involvement in reading: The effects of language experience

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The goal of this study was to examine whether readers of Hebrew generalize their native-language processing strategies to the representation of English words. To this end, we examined lateralization patterns in the lexical decisions of native English and Hebrew readers to English stimuli, and compared the performance of native Hebrew speakers in English and in Hebrew. We used both unilateral and bilateral presentation modes, which allowed us to assess interhemispheric communications, and manipulated the morphological complexity of the stimuli. The results showed the following pattern: English speakers showed an RVFA for words and not for nonwords, with interhemispheric patterns suggesting independent LH processing and dependent RH processing of words. Hebrew speakers showed no visual field advantage in English, whereas they show an RVFA when they read Hebrew. Findings suggest that the division of labor between the two hemispheres is determined by linguistic experience, whereas the effects of morphological manipulations reflect the structure of the language of the test.

The majority of research on the neuropsychological aspects of reading has been done with English speakers reading English. Therefore, to test the generality of models of brain functioning during reading it is necessary to examine patterns shown by native speakers of other languages. A number of

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authors have explored hemispheric functioning in readers of non Indo-European languages (e.g., Eviatar & Ibrahim, 2007; Ibrahim & Eviatar, 2009; Laine & Koivisto, 1998). These studies have found different patterns: For example, examining the effects of morphology in lateralized paradigms with native speakers of English (Burgess & Skodis, 1993) and French (Koenig, Wetzel, & Caramazza, 1992), which are both Indo-European languages, revealed that only the LH is sensitive to the morphological structure of words. However, in Finnish, which is not an Indo-European language, research has revealed that although morpheme-based lexical access is more accurate in the LH, it is a task which the RH is also capable of performing (Laine & Koivisto, 1998). Semitic and Indo-European languages also differ in their morphology. A number of studies have explored the underlying representation of words in the lexicon of Semitic languages, and have proposed that this representation is different from words in Indo-European languages (Feldman, Frost, & Pnini, 1995). Eviatar and Ibrahim (2007) found that there are differences in the division of labor and in sensitivity to morphological complexity between the cerebral hemispheres among English, Hebrew and Arabic speakers performing a lexical decision task in their native language. They suggested that these differences arise from structural differences between the languages and the processes required to decode their orthography. On the basis of these findings we hypothesize that linguistic experience shapes sensitivity to morphological complexity and hemispheric division of labor in the early stages of reading.

The goal of the present study is to examine this hypothesis closely, and to test whether the findings reported in that paper are a result of the language of the test, or whether they are characteristics of the readers of these three different languages, no matter what language they read. That is, previous findings from our lab (Eviatar & Ibrahim, 2007; Ibrahim & Eviatar, 2009) have suggested that there are differences in the hemispheric division of labor during a lexical decision task between readers of English, Hebrew, and Arabic, when they perform the task in their native language. The question examined here is, are these differences a stable characteristic of how native readers of different languages read in general, or are they specific to the language in which the task is presented? Do structural differences between languages have permanent effects on hemispheric interaction, or are these task and language specific?

English and Hebrew differ in three major ways that can affect performance asymmetries in divided visual field paradigms – in reading direction (Eviatar, 1997), in orthography/phonology relations (Eviatar, 1999; Eviatar, Ibrahim, & Ganayim, 2004), and in morphological structure (Eviatar & Ibrahim, 2007). In this paper the main focus will be the effect of morphology on hemispheric specialization in the initial stages of word recognition.

1. Morphology in English and Hebrew

Differences between the languages in morphological structure may be hypothesized to affect hemispheric involvement during lexical access. 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. Thus, a morphologically simple word in English (like “act”) can be made complex by adding a derivational morpheme to it (e.g., “actor”). Hebrew is characterized by a nonconcatenative, highly productive derivational morphology (Berman, 1978). Most words are derived by embedding a root into a morpho-phonological word pattern. 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 Hebrew the word (KATAVA) consists of the root KTV (whose semantic space includes things having to do with writing), and the phonological pattern _A _A _A. The combination results in the word ‘report or article’. 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 (Berent, 2002; Deutsch, Frost, & Forster, 1998; Feldman et al., 1995; Frost & Bentin, 1992; Frost, Forster, & Deutsch, 1997) have explored the effects of the morphology and orthography of Hebrew on lexical access and the structure of the mental lexicon. Two conclusions from these studies are especially relevant to the present study. The first is 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. The second is that morphologically complex Hebrew words cannot be read via incremental parsing (Eviatar & Ibrahim, 2004). 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 another Semitic language, 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 initial 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" (p.364), that is, after extraction of the root. Prunet, Beland, and Idrissi (2000) reported 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 also 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.

Proficient readers of Hebrew usually identify the root in the context of a word quickly and easily. Accessing the phonological form of the word requires guessing the vowels, because these are omitted from the orthography in all written materials except children's books, liturgical texts and poetry. Thus the unvowelized orthography in Hebrew is considered deep – the relationship between orthography and phonology in not straightforward. In English, all the vowels are written, but this relationship is still not straightforward: English is classified as a morpho-phonemic writing system because it incorporates both morphological and phonemic properties (Breznitz, 2004) – words that are phoneme-based correlatives of the actual sound (e.g., "cat") and words that are spelled according to their original morpheme (e.g., "muscle" is connected to "musculature" and to the original Latin "musculas"). This property of the English language generates its complex spelling system (Coulmas, 1996), also resulting in a deep orthography. The two languages (English and Hebrew) use alphabetic orthographies, and are considered deep orthographies, but for different reasons: reading English is not straightforward because of the irregularity in grapheme–phoneme relations, and reading unvowelized Hebrew and Arabic is not straightforward because vowel information is omitted.

2. Reading and hemispheric specialization

Another factor that can affect hemispheric specialization for lexical access is the status of the language in the cognitive system. The literature about the neural basis of bilingualism is not without debate. One position is that there is one neural representation of multiple languages (Moretti et al., 2001; Paradis, 1990). Evidence supporting this view comes from studying bilingual aphasics (Aglioti, Beltramello, Girardi, & Fabbro,1996; Ojemann, 1983) and from studies using neuroimaging techniques. (e.g., Briellman et al., 2004; Klein, Milner, Zatorre, Zhao, & Nikelski, 1999). Another position is that bilingual persons may have distinct cortical language areas (Dehaene, Dupoux, & Mehler, 1997), or that second language processing involves more RH activations than native language processing (e.g., Ding et al., 2003).

Differences in the division labor between the hemispheres during reading due to differences in phonological, orthographic and morphological factors, have been tested extensively in our lab. In two studies that used a lateralized syllable identification paradigm (Eviatar, 1999; Eviatar & Ibrahim, 2004), we tested differences in indexes of processing strategy among readers of Hebrew, Arabic, and English. Eviatar (1999) compared the lateralization patterns of native Hebrew and English readers, while they were identifying the elements of a trigram. The stimuli were consonant-vowel-consonant (CVC) nonsense syllables in their native language, a second language, or made up of three numbers (which are written identically in the two languages). For English speakers, the same qualitative difference in hemispheric functioning that has been reported in previous studies was found, (e.g., Hellige, Cowin, & Eng, 1995), a pattern interpreted as reflecting sequential processing in the LVF (RH), and a pattern interpreted as reflecting a more parallel processing strategy in the RVF (LH). Hebrew speakers showed the opposite asymmetry when they were presented with CVC trigrams in Hebrew, in English (their second language), or number trigrams. Eviatar (1999) suggested 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. For example, naming a CVC trigram requires lexical access in Hebrew, but not in English. In that study, it seems that Hebrew speakers were using the same strategy in both Hebrew and English.

Eviatar and Ibrahim (2004) compared the patterns of native Hebrew and English readers to those of Arabic. The Hebrew and Arabic speakers showed the same hemispheric difference pattern – more sequential processing in the RVF than in the LVF. This was different from the one shown by English speakers, who showed the opposite pattern. Eviatar and Ibrahim (2004) interpreted their findings as showing reflecting differences in hemispheric division of labor of while reading languages that differ in morphological structure and orthography.

3. The basis for the current research

Eviatar and Ibrahim (2007) performed a series of lateralized experiments using unilateral and bilateral presentations that are the basis for the present study. In the bilateral condition, two stimuli were presented on each trial, one in each visual field, and the participants were cued which of these was the target and which was to be ignored. The main focus of Eviatar and Ibrahim's (2007) experiment was the functional organization of sensitivity to the morphological structure of words in the two cerebral hemispheres. Morphological complexity was defined differently in English and in the Semitic languages (Hebrew and Arabic): in English, morphologically simple words were monomorphemic words (e.g., act) and morphologically complex words were derivations (e.g., actor); in Hebrew and Arabic, morphologically complex words were words with transparent roots (i.e., roots that can be easily extracted, like in the examples above: KATAVA in Hebrew), and morphologically simple words were words with a non-transparent root (i.e., words in which the root is not extracted, like PSANTER in Hebrew).

Eviatar and Ibrahim (2007) tested English-, Hebrew- and Arabic speakers performing a lexical decision task in their native language. Overall, in all languages, words were recognized faster than nonwords (effect of lexicality), and a right visual field advantage (RVFA) was found for words (suggesting LH specialization for this task, for words). The main conclusions regarding morphology are presented here briefly. When English speakers made lexical decisions upon stimuli (both words and nonwords) presented to the RVF, morphological complexity affected RT; however, when the stimuli were presented to the LVF, morphological complexity had no effect on RT. This processing dissociation suggests that the LH is sensitive to morphological complexity and the RH is not, and replicates previous findings (e.g., Burgess & Skodis, 1993). In Hebrew and Arabic, a different processing dissociation was found: complex words were processed faster and more accurately than simple words, while complex nonwords were processed more slowly than simple nonwords, in both visual fields. This suggests that morphological transparency facilitates recognition of words, and slows down recognition of nonwords, and that both hemispheres are sensitive to morphological structure in these two Semitic languages.

The sensitivity in the LVF to morphological complexity in Hebrew and Arabic could have resulted from either RH sensitivity to morphology in these languages, that is, independent RH processing of LVF stimuli, or, from callosal transfer of LVF stimuli to the LH. In order to test hemispheric cooperation in processing morphology, Eviatar and Ibrahim (2007) defined three indices of hemispheric integration. These are described in detail because they are used in the present experiment.

The first index has been mentioned, a *processing dissociation*: this is an interaction between a stimulus variable (for example, lexicality or morphological complexity) and the visual field to which it was presented. The logic is the following: 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. This was the logic used by Koenig et al. (1992) and by Burgess and Skodis (1993) when they suggested, on the basis of finding effects of morphology only in the RVF, that only the LH is sensitive to morphological structure. Eviatar and Ibrahim (2007) found this pattern for English speakers with stimuli in English, while both Hebrew and Arabic speakers, performing the task in their native language showed effects of morphology in both visual fields. We suggested that this pattern is consistent with the hypothesis that while reading the Semitic languages, both hemispheres must be able to process morphology.

The two additional indices resulted from the use of bilateral and unilateral presentations. Eviatar and Ibrahim (2007) examined the effects of *distractor status* and *the bilateral effect* to characterize interhemispheric interaction. The logic of the distractor status measure is the following: if LVF stimuli are processed independently by the RH, then the lexical status or morphological complexity of the distractor presented to the LH should not affect performance. However, if the RH draws upon LH resources to perform the task, then we will see an effect of the distractor. For example, Iacoboni and Zaidel (1996) found such an effect in English for words, but not for nonwords. They concluded that this is evidence that the RH can reject nonwords independently, but draws upon LH processes to accept words. Thus, in Eviatar and Ibrahim's (2007) experiment, a *Distractor* was manipulated in order to test interhemispheric interaction: if interhemispheric interaction is involved (as, for example, with stimuli presented in the LVF being transferred via the corpus callosum to the LH for processing) then the identity of the distractor should affect responses to the target. Iacoboni and Zaidel (1996) suggested such an effect – a lexical congruity effect: when the distractor is similar to the target in lexicality (i.e., both are words or both are nonwords), faster processing will occur.

In addition, comparison of the unilateral and bilateral conditions in equivalent language groups can test possible communication between the two hemispheres. Boles (1990) reported that performance asymmetries are larger when stimuli are presented bilaterally than when they are presented unilaterally. He called this "the bilateral effect", and proposed that it 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 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.

The main conclusions of Eviatar and Ibrahim (2007) regarding the *distractor status* and the *bilateral effect* in English-, Arabic- and Hebrew-speakers reading their native language are the following: In English, the results support hemispheric independence for the LH, and interhemispheric cooperation in the processing of targets presented to the LVF. In Arabic, the results support a *direct access model* for words, where each hemisphere processes the stimuli presented directly to it, and hemispheric cooperation in processing nonwords. In Hebrew, sensitivity to the lexical status of the distractor in both visual fields suggested that both hemispheres participate in lexical decision involving words and nonwords.

4. Distinguishing between different types of cognitive processes

In the present study, native Hebrew readers were tested in English, and their results compared to those of native English speakers, using the same paradigm reported in Eviatar and Ibrahim (2007). The goal is to try to distinguish between two parts of the processing system. The first part is that which is dynamic and done online, and is thus sensitive to the structural characteristics of the language being read ("language-driven"; in this experiment - English). A prototypical result representative of this part will be result patterns of Hebrew-speakers reading English which are *similar* to the result patterns of English speakers reading English (as tested in this experiment), while at the same time these result patterns are *different* from the result patterns of Hebrew speakers reading their native language (as reported by Eviatar & Ibrahim, 2007). The second part is that which is characteristic of the system in general. This part of the system is not sensitive to the structural characteristics of the language being read at the moment; it represents the way in which a person reads *any* language ("experience-driven"; in this experiment, the reading experience of Hebrew-speakers). A prototypical result representative of this part will be Hebrew-speakers showing the *same* result patterns when they read English (in this experiment) and when they read their native language (as reported by Eviatar & Ibrahim, 2007), while at the same time these result patterns are *different* from those of English speakers reading English.

Thus, this experiment can identify four types of cognitive processes. First, it can identify universal language reading processes, which are characteristic of any brain reading any language, by pointing to result patterns common to all subjects in this experiment as well as in an experiment in which English - and Hebrew-speakers read their native language (e.g., Eviatar & Ibrahim, 2007). Second, it can identify characteristics of hemispheric processes that may be specific to readers of Semitic languages ("experience-driven processes"). Third, it can identify characteristics of the English language on reading processes in any person's brain, by pointing to "language-driven" processes: result patterns common to all subjects in this experiment which will be different from the result patterns Hebrew-speakers show when they are reading English (Eviatar & Ibrahim, 2007). And lastly, it can identify an interaction between these last two types of processes, by pointing to unique patterns which characterize the result patterns of a certain native language speaker reading a specific language.

5. Methods

5.1. Design

The dependent variables in this research were median response times (RT) and percent of errors in a lexical decision task. The independent variables of the unilateral presentations were visual field (left visual field - LVF vs. right visual field - RVF), lexicality (words vs. nonwords), and morphological complexity (simple vs. complex). All these were within-group factors. A fourth variable, native language (English or Hebrew), was a between-group factor. In the bilateral presentations, the same variables were used and a fifth variable – distractor status (whether it was a word or a nonword, and whether it was morphologically simple or complex) was added. For example, a target that is a morphologically complex word was paired with a distractor that was another morphologically complex word, a morphologically simple word, a morphologically complex nonword, or a morphologically simple nonword.

5.2. Participants

The participants were 40 students at Haifa University, 20 in each native language group. The native English speakers were recruited from the summer Overseas Program. All were American, and were paid for their participation. The native Hebrew speakers were all students at Haifa University. All of the Hebrew speakers were highly proficient in English. All had begun to learn English in 3rd grade, and had passed high school matriculation exams, and university entrance exams, which include English proficiency measures. Most completed the experiments for course credit, with some receiving payment instead. All were right-handed, neurologically normal, and had normal or corrected vision.

5.3. Stimuli

A list of 80 words and a list of 80 nonwords in English were compiled. Of the words, 40 were morphologically simple and 40 were morphologically complex. Morphologically simple words were monomorphemic (e.g., act). Morphologically complex words were derivations (e.g., actor). The lists were equated on the average frequency of the words and for initial letters. Nonwords were also morphologically manipulated. Morphologically simple nonwords were derived from the simple words by changing one or two letters (e.g., dittle), and complex nonwords were illegal combinations of real morphemes (e.g., gapty). The stimuli are listed in Appendix A.

5.4. Procedure

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 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, one stimulus (the 'target') appeared in each trial, either in the RVF or the LVF. In the bilateral condition, two stimuli appeared in each trial, one in each visual field. One of the stimuli was underlined, indicating that it was the target (and that the other stimulus should be ignored). In both conditions, the stimuli were followed by a pattern-mask that remained on screen until the participant responded or 3 s had passed. The screen was blank for 2 s, and the next trial began. Participants responded on the keyboard by pressing the up-arrow if the target was a real word and the down-arrow if it was not.

6. Results

Three stages of analysis were done, and these revealed native language interaction effects, bilateral presentation effects and distractor status effects. In all analyses, median RT and percent errors were measured. Trials in which RT was shorter than 100 ms or longer than 3000 ms were excluded from analysis

6.1. Native language effects with unilateral presentation

Correlations between median RT and errors revealed no speed accuracy tradeoffs. The median RT and % error scores were analyzed with a mixed ANOVA using native language as a between groups factor, and lexicality (words vs. nonwords), morphological complexity (complex vs. simple) and VF (LVF vs. RVF) as within subjects factors. The cell means are illustrated in Fig. 1. The four way interaction was not significant in RT or errors. In RT, the 3-way interaction between language, lexicality and VF approached significance, $F(1,38) = 3.27$, $p = .078$. It can be seen in Fig. 1 that this is due to a smaller visual field advantage for nonwords and complex words for Hebrew speakers than for English speakers. The two-way interaction between morphology and VF is significant in RT, $F\ (1, 38) = 5.10$, $p < .05$, but not in errors. It can be seen that both language groups reveal the effect of morphological complexity on RT in the RVF, not in the LVF. The two-way interaction between language and VF was significant in both RT ($F(1,38) = 7.38$, $p < .01$) and in errors ($F(1,38) = 4.9$, $p < .05$). It can be seen that the RVF advantage appears for all stimuli for English speakers, but less consistently for Hebrew speakers. The interaction between language and morphology was significant in RT ($F(1,38) = 5.39$, $p < .05$) with the difference between simple and complex stimuli smaller in English speakers (803 ms vs 814 ms) than in Hebrew speakers (990 ms vs 1045 ms). In addition, the main effect of visual field was significant in errors ($F(1,38) = 15.45$, $p < .001$), the main effect of lexicality was significant in RT, $F\ (1,38) = 39.31$, $p < .0001$, and the main effect of morphology was significant in both RT, ($F(1,38) = 11.86$, $p < .01$) and errors ($F(1,38) = 49.10$, $p < .0001$), as was the main effect of language (RT:$F(1,38) = 18.42$, $p < 0001$; errors: $F(1,38) = 15.96$, $p < .0001$).

Planned comparisons revealed that the simple main effect of morphological complexity in RT for both language groups was significant only in the RVF, not in the LVF, (for English speakers: nonwords: $F\ (1,38) = 9.46$, $p < .01$; words: $F(1,38) = 13.43$, $p < .01$; for Hebrew speakers: nonwords $F(1,38) = 11.38$, $p < .01$; words: $F(1,38) = 4.63$, $p < .05$). For errors, a similar but not identical pattern is found, where for Hebrew speakers, again the main effect of complexity is only significant in the RVF (for nonwords: $F\ (1,38) = 5.95$, $p < .05$; for words: $F(1,38) = 14.21$, $p < .001$) while for English speakers, the effect is significant in both visual fields for nonwords (LVF:$F(1,38) = 14.29$, $p < .001$; RVF:$F(1,38) = 20.16$, $p < .001$), and is not significant for words in either visual field.

6.2. Test language effects

In order to examine the effects of test language, we compared the results of the Hebrew speakers on the test in English to the patterns that they evinced when performing the task in their native language (those data are described in detail in Eviatar & Ibrahim, 2007).

Thus, we used a 4-way within-subject ANOVA with test language, lexicality, morphology, and visual field as independent variables. The results revealed a 3-way interaction in error scores between test

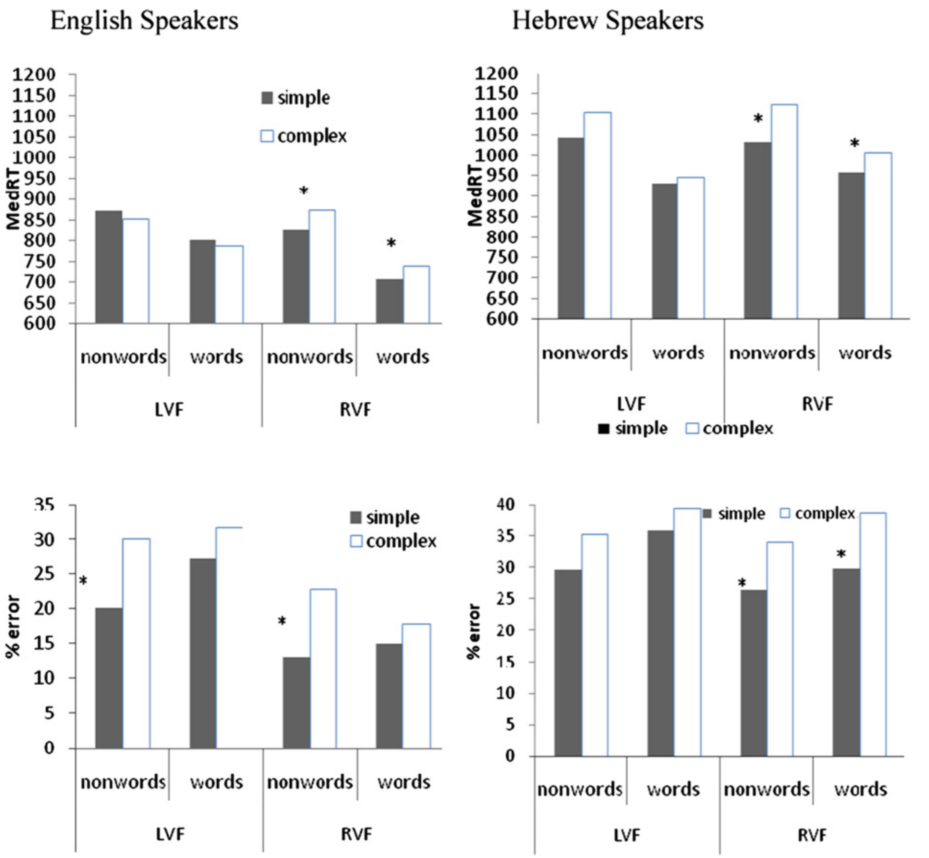

Fig. 1. Mean median RTs and % error for English and Hebrew Speakers.

language, morphology, and visual field. This pattern is illustrated in the top panel of Fig. 2, and it can be seen that it results from the fact that the effects of morphology are not significant in Hebrew (L1), whereas there is a significant effect in the RVF, but not in the LVF in English (for words: $F(1,19) = 14.21$, $p < .005$; for nonwords: $F(1,19) = 5.95$, $p < .05$). In the error data the interaction of test language and morphology was significant, $F(1,19) = 8.64$, $p < .01$; as was the main effect of test language, $F(1,19) = 24.8, p < .001$. The RT results revealed two 2-way interactions: between test language and visual field $F(1,19) = 4.89, p < .05$, with the participants showing faster responses in the RVF than in the LVF in Hebrew (895 ms vs. 913 ms) but not for English (1029 ms vs. 1006 ms); and between test language and morphology, $F(1,19) = 8.42$, $p < .01$, with an insignificant difference between complex and simple stimuli in Hebrew (900 ms vs. 908 ms) and a larger difference in English (1054 ms vs 990 ms). The main effect of test language was also significant, $F(1,19) = 15.39$, $p < .001$, with responses faster in Hebrew (904 ms) than in English (1018 ms). It can be seen that morphological complexity affects both errors and response times in the RVF in English, not in Hebrew. The RT patterns can be seen in the bottom panel of Fig. 2.

6.3. Bilateral presentation effects

The data from the bilateral presentations were analyzed in three ways. First of all, given that this was run on different samples of participants, the data were analyzed without the factor of 'distractor' in

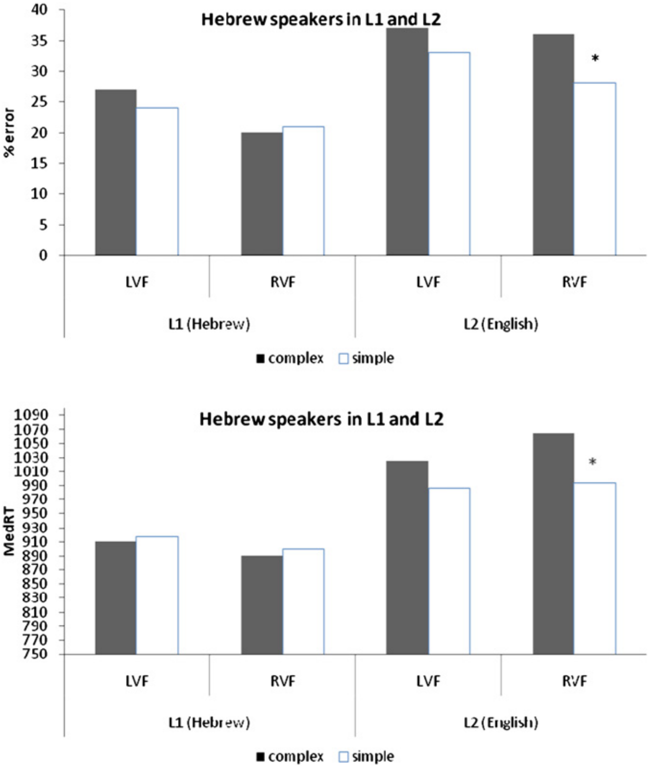

Fig. 2. Effects of morphological complexity in L1 (Hebrew) and in L2 (English).

order to replicate the patterns found with the unilateral presentations. Second, in order to tease out hemispheric interactions as detailed in the introduction: the bilateral effect (BE), where interhemispheric interaction results in larger visual field differences in the bilateral than in the unilateral presentation conditions, was computed. Thirdly, we examined effects of distractor type: where effects of distractor type suggest interhemispheric interaction, whereas no effects of distractor type suggest hemispheric independence.

6.3.1. *Replication*

Analysis of the bilateral condition without the distractor variable revealed the pattern illustrated in Fig. 3. In RT the 4-way interaction between language, lexicality, morphology and VF was significant, $F(1,38) = 8.43$, $p < .01$. It can be seen that this is due to 2 patterns: English speakers show a significant difference between simple and complex words, whereas Hebrew speakers show this pattern for nonwords. In addition, Hebrew speakers show a marginal effect of morphology for words in the LVF, $F(1,19) = 3.92$, $p = .06$, while the effect of morphological complexity for English speakers for nonwords in the RVF is also marginal, $F(1,19) = 3.77$, $p = .06$. Language did not interact with any other factor in either RT or errors, and most importantly for us, the morphology by visual field interaction in RT is significant, $F(1,38) = 4.71$, $p < .05$. In errors, language did not interact with any of the other factors. The bottom panel of Fig. 3 summarizes the differences between the presentation conditions over all of the participants. The important finding here is that effects of morphological complexity occur in the RVF with both paradigms.

6.4. *The bilateral effect*

According to Boles (1990), processes that require communication between the hemispheres will result in larger visual field differences with bilateral than with unilateral presentations. Thus,

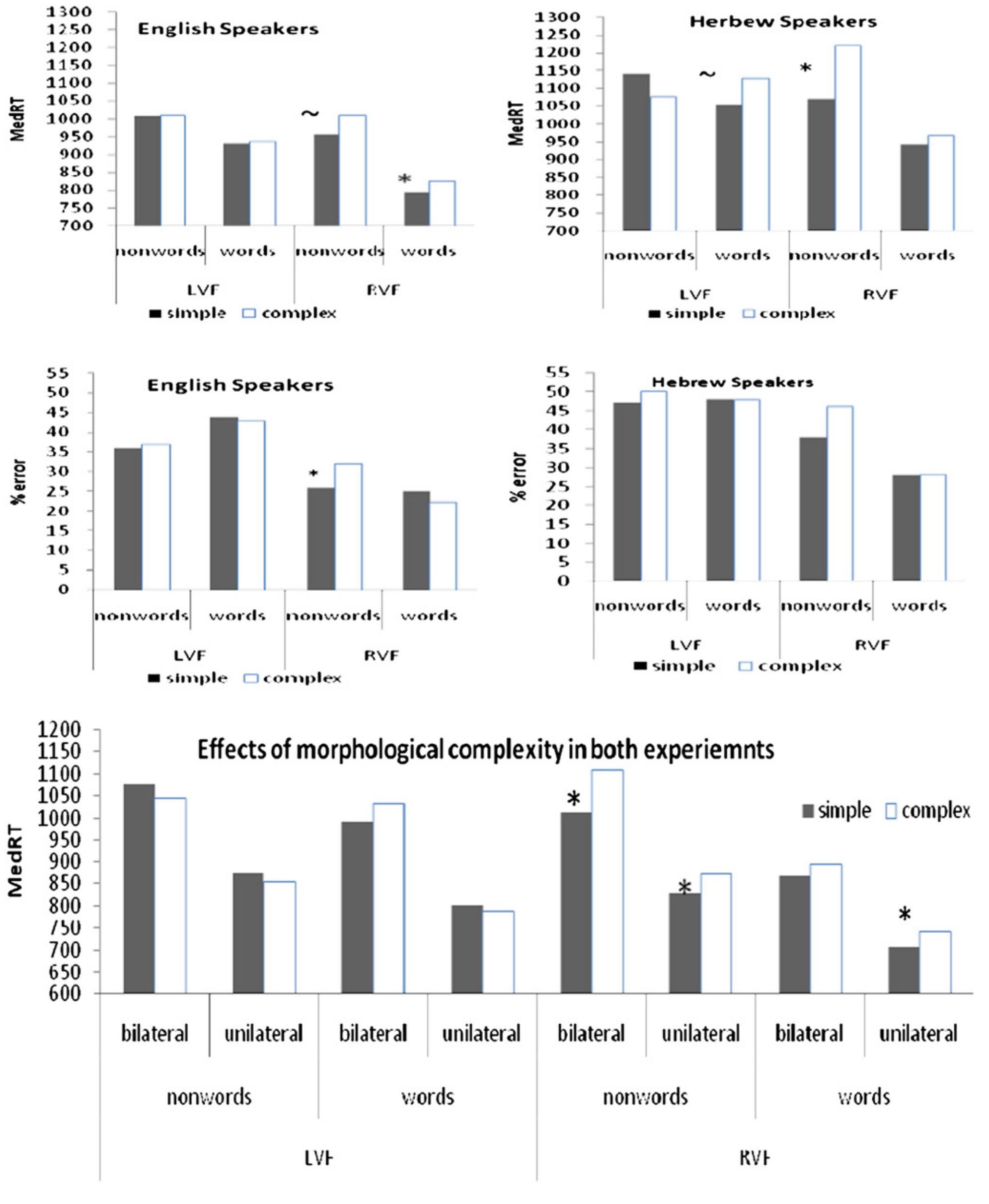

Fig. 3. Replication of the findings from the unilateral presentation with bilateral presentations. * = $p < .05$, ~ = $p < .09$.

comparison of the visual field differences can indicate hemispheric independence or interdependence. In order to test the effect of presentation mode explicitly, we computed, the visual field difference (LVF-RVF for both median RTs and percent error) in each lexicality by morphology condition in all the language by presentation mode (unilateral vs. bilateral) groups. An ANOVA with presentation mode as a between groups factor and lexicality and morphological complexity as within subject factors was computed for each language group. The differences between the visual fields in both median RTs and percent errors were the dependent variables. The ANOVA revealed no effects of presentation mode for

English speakers, and a significant 3-way interaction for Hebrew speakers in RT, $F(1,38) = 8.41$, $p < .01$. In addition, for the Hebrew speakers, the main effect of presentation mode was significant for both RT and errors ($F(1,38) = 3.71$, $p = .06$; $F(1,38) = 5.09$, $p < .05$). These patterns are shown in Fig. 4.

It can be seen that for both groups, the visual field advantage is larger in the bilateral condition for words than for nonwords. Planned comparisons revealed that the bilateral effect is significant for Hebrew speakers for both complex and simple words but not for nonwords: RT: complex words, $F(1,38) = 8.31$, $p < .01$; simple words: $F(1,38) = 6.45$,$p < .05$; errors complex words, $F(1,38) = 4.76$, $p < .05$; simple words: $F(1,38) = 2.9$,$p = .09$.

6.5. Effects of distractor type

The data from the bilateral conditions were analyzed to see if the lexical status of the distractor affected lexical decisions on the targets. To test this, analyses of the simple main effect of the lexical type of the distractor (same or different) in each of the lexicality by morphology by visual field conditions for each language group were performed. The results of these analyses are presented in Table 1.

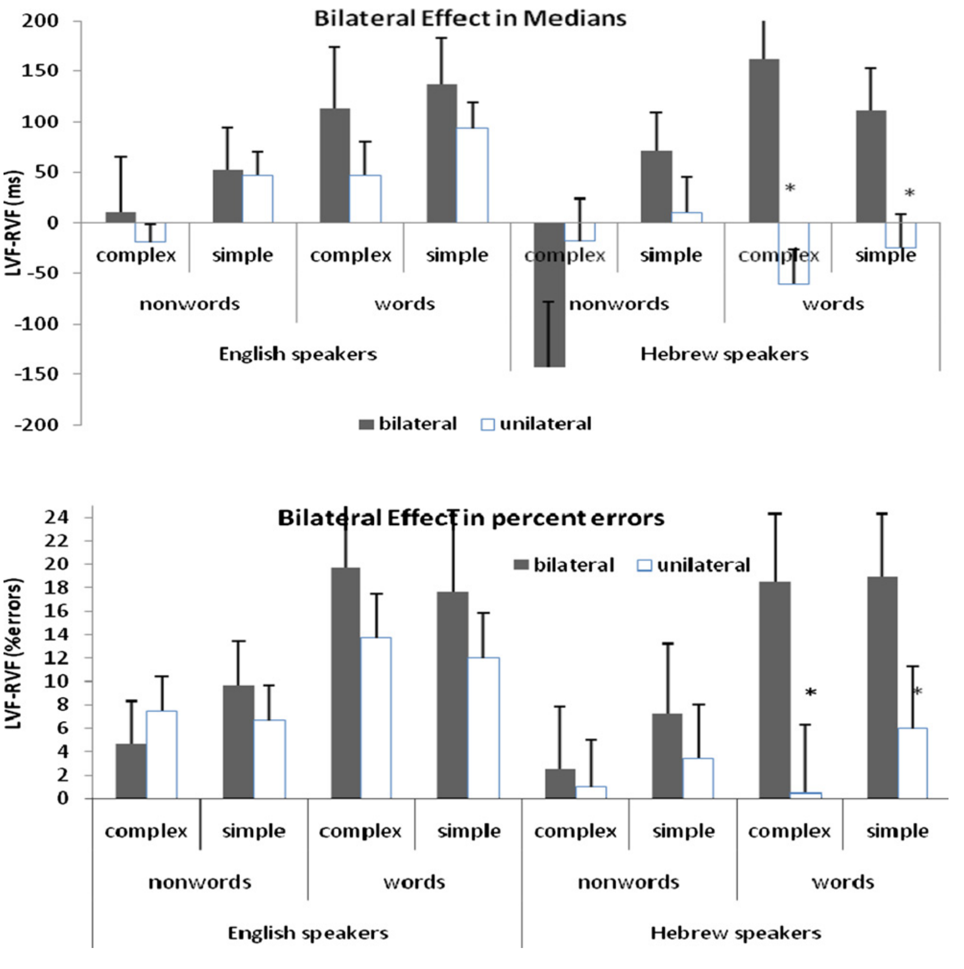

Fig. 4. Bilateral Effects in L1 (Hebrew) and in L2 (English).

Table 1
Statistically significant simple main effects of the lexical status of the distractor (same or different) on the RT and error rates of lexical decisions on targets in the bilateral condition.

Hebrew speakers (df = 1,19)								
	Nonwords				Words			
	Complex		Simple		Complex		Simple	
	MedRT	%error	MedRT	%error	MedRT	%error	MedRT	%error
LVF	$F = 6.33$, $p < .05$	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RVF	n.s.	n.s.	n.s.	$F = 3.77$, $p = .067$	n.s.	$F = 6.06$, $p < .05$	n.s.	$F = 3.42$, $p = .08$
English speakers (df = 1,19)								
	Nonwords				Words			
	Complex		Simple		Complex		Simple	
	MedRT	%error	MedRT	%error	MedRT	%error	MedRT	%error
LVF	$F = 3.88$, $p = .063$	$F = 3.58$, $p = .07$	n.s.	n.s.	$F = 6.88$, $p < .05$	n.s.	n.s.	n.s.
RVF	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Significant effects are highlighted. MedRT = median reaction time; LVF = left visual field; RVF = right visual field.

A significant effect of distractor type is interpreted as indicating that the hemisphere contralateral to the target's visual field used resources of the other hemisphere while processing the target. Several patterns are revealed in Table 1. First, there are significant effects in the two language groups, but only for complex stimuli. For English speakers, a significant effect was found in the LVF, for complex words. In addition, there are marginal effects in the LVF for complex nonwords in this group. These data, reported in Eviatar and Ibrahim (2007), replicate the finding of Iacoboni and Zaidel (1996) with English speakers. The data suggest that the LH performed the lexical decision task independently, and that the RH utilized LH resources while performing the task.

The speakers of Hebrew show effects of distractor type in both visual fields (as they do in Hebrew, see Eviatar & Ibrahim, 2007). This pattern was interpreted there, as it is here, as reflecting inter-hemispheric dependence, with both hemispheres participating in the lexical decision of stimuli in both visual fields.

7. Discussion

This study was designed to examine whether readers of Hebrew generalize their native-language processing strategies to the representation of English words. To achieve this goal, we compared the performance of native speakers of English and Hebrew in a word-recognition (lexical decision) task with English words presented horizontally to each of the two hemispheres (the same paradigm reported in Eviatar & Ibrahim, 2007). We used both unilateral and bilateral presentation modes, which allowed us to assess interhemispheric communications, and manipulated the morphological complexity of the stimuli. Our experiments yielded different patterns of hemispheric functioning for lexical status and for morphological complexity.

7.1. Unilateral conditions

7.1.1. Lexical status

For lexical status, in the unilateral conditions the canonical visual field by lexicality interaction was found only for English speakers. As shown in Fig. 2 and reported in detail in Eviatar and Ibrahim (2007), Hebrew speakers revealed a smaller RVF advantage in Hebrew than did English speakers in English. Thus, the results of the Hebrew speakers performing the task in English, their L2, can be seen as similar to the pattern they show in Hebrew, their L1. This is consistent with findings reported by Hull and Vaid (2007), who found similar lateralization patterns in the languages of bilinguals. We interpret these results as reflecting the interaction of hemispheric abilities with the different demands of the different orthography, and the strategy of lexical decision is set by the characteristics of the language people learn to read first; that is, they are experience driven (Hull & Vaid's "anchoring hypothesis").

However, these data patterns are also consistent with an alternative interpretation: In the unilateral conditions, it can be seen that the RVF advantage appears for all stimuli for English speakers, but less consistently for Hebrew speakers. This is consistent with other reports of less consistent lateralization for L2 (e.g., Bloom & Hynd, 2005; Ding et al., 2003), and also with the recruitment hypothesis. This is the hypothesis that when tasks become more difficult, more brain areas are involved in their processing (e.g., Just, Carpenter, Keller, Eddy, and Thulborn (1996), Yang, Edens, Simpson, and Krawczyk (2009)), suggesting that as language tasks become more difficult, the RH is recruited and becomes more involved.

Thus, we have a data pattern that is consistent with two different interpretations. We argue that Hebrew speakers reveal smaller visual field differences in English because they are processing the stimuli similarly to the way they process Hebrew, the language they learned to read first (in line with Hull & Vaid's "anchoring hypothesis"). The recruitment hypothesis argues that Hebrew speakers reveal smaller differences than English speakers because the task is more difficult for them (they are reading L1, whereas English speakers are reading L1). We believe that the our interpretation makes more sense in this case, because Hebrew speakers reveal bilateral processing when they read Hebrew, which is their first language, and should not be more difficult than English for them.

7.1.2. Morphological complexity

The effects of morphology were the same in the two language groups, supporting the hypothesis that English orthography requires morphological sensitivity only for stimuli presented in the RVF (directly to the LH), irrespective of whether English is the participant's first or second language.

The native languages of the participants tested in these experiments (English and Hebrew) differ in three major ways: in reading direction, in the manner in which phonology is represented in orthography, and in the morphology of the language. Previously we have shown that reading direction and orthography–phonology relations can affect attentional habits during letter matching tasks (Eviatar, 1995; Eviatar & Ibrahim, 2004; Eviatar et al., 2004). The findings presented here and in Eviatar and Ibrahim (2007) suggest that morphological structure also affects hemispheric involvement in word identification. Specifically, planned comparisons revealed that the simple main effect of morphological complexity in RT for both language groups was significant only in the RVF, not in the LVF. For errors, a similar but not identical pattern is found, where for Hebrew speakers, again the main effect of complexity is only significant in the RVF, while for English speakers, the effect is significant in both visual fields for nonwords, and is not significant for words in either visual field. Therefore, the results showed that both hemispheres are sensitive to morphological structure in the Hebrew language, but that when native speakers of these languages read English, morphological sensitivity is relatively stronger in the RVF than in the LVF. In both groups morphologically simple stimuli were processed more accurately than morphologically complex stimuli. When Hebrew-speakers read their native language, they showed the opposite effect: morphologically complex stimuli were identified faster than morphologically simple stimuli (Eviatar & Ibrahim, 2007). Although this finding depends on the definition of morphological complexity, it points to a language factor process of the English language: for a native speaker of any language, it is easier to process a morphologically simple stimulus than a morphologically complex stimulus *in English*.

7.2. Bilateral condition

The bilateral condition allowed testing of three indices of hemispheric integration that helped to validate and identify language and external factor processes, and to check the division of labor between the hemispheres in the three language groups. The data from the bilateral presentations were analyzed in three ways. First of all, given that this was run on different samples of participants, the data were analyzed without the factor of 'distractor' in order to replicate the patterns found with the unilateral presentations. Second, in order to tease out hemispheric interactions as detailed in the introduction, the bilateral effect (BE), where interhemispheric interaction results in larger visual field differences in the bilateral than in the unilateral presentation conditions, was computed. Thirdly, we examined effects of distractor type: where effects of distractor type suggest interhemispheric interaction, whereas no effects of distractor type suggest hemispheric independence.

Analysis of the bilateral condition without the distractor variable revealed that English speakers show a significant difference between simple and complex words, whereas Hebrew speakers show this pattern for nonwords. In addition, Hebrew speakers show a marginal effect of morphology for words in the LVF, while the effect of morphological complexity for English speakers for nonwords in the RVF is also marginal. Language did not interact with any other factor in either RT or errors, and most importantly for us, the morphology by visual field interaction in RT is significant. In errors, language did not interact with any of the other factors. This effect is summarized in the bottom panel of Fig. 3, which shows that in both experiments, significant effects of morphological complexity occurred only in the RVF, across all the participants.

As mentioned above, the bilateral conditions allowed us to directly test hypotheses about hemispheric independence and interdependence. Recall that the Bilateral Effect is defined as the difference in visual field advantage in the unilateral versus the bilateral experiments. The logic is that under hemispheric *in*dependence, visual field differences should be equivalent in the two conditions, whereas under hemispheric *inter*dependence, the visual field difference will be larger in the bilateral than in the unilateral conditions. As shown in Fig. 4, this was the case for the Hebrew speakers, not for the English speakers. Thus, this index suggests more interhemispheric interaction for Hebrew speakers reading English than for English speakers reading English. As mentioned above, this is similar to the pattern that the Herbrew speakers reveal in Hebrew. This is in line with research that shows that the specifity of L1 is crucial in the involvement of the RH in processing verbal stimuli (e.g., Lee et al., 2008; Wattendorf & Festman, 2008). This means that learning Hebrew (and not English) as L1 triggers RH involvement in processing written verbal stimuli.

The second index that taps interhemispheric relations is the effect of distractor status on responses to targets. Recall that under hemispheric *in*dependence, the lexical status of the distractor should not affect lexical decision of the target, whereas under hemispheric interdependence, the lexical status of the distractor should hinder the decision of the target when it is different, and faciliatate the decision when it is the same. As shown in Table 1, For English speakers, we replicated the findings reported by Iacoboni and Zaidel (1996), with participants revealing an effect of distractor status only in the LVF. This was interpreted by them and by us, as reflecting independent processing of RVF stimuli by the LH, and interdependent processing of LVF stimuli, with the RH requiring resources from the LH to perform the task. Effects of distractor status were found for Hebrew speakers in both visual fields. This suggests interhemispheric transfer of information for stimuli presented to both visual fields, and similar to the findings reported by Eviatar and Ibrahim (2007) for these Hebrew speakers reading Hebrew. This may result from the unique and non-linear morphological aspects of Semitic languages like Hebrew (Eviatar, 1999), and is expected to appear when these subjects read *any* language.

To summarize, we proposed that our design can reveal four types of processes: general universal language processes, language driven processes (patterns resulting from the demands made by a particular language structure and orthography), experience driven process (patterns resulting from the charactersitistics of the language the participants learned to read first, that will occur for all languages they read), and interactions between these types of processes. The results of the experiments presented here allow two major conclusions: 1) sensitivity to morphology is driven by the language of the test: when Hebrew speakers read Hebrew, both hemispheres are sensitive to morphology. But when native Hebrew speakers read English, only the LH is sensitive to morphology, as it is in native English readers. 2) lexical decision is driven by the language experience of the participants. When making lexical decisions in Hebrew, Hebrew readers reveal patterns suggesting interhemispheric interactions, which are different from the patterns revealed by English speakers reading English. When they are reading English, Hebrew speakers seem to utilize the same interhemispheric strategies that they do in Hebrew. These patterns emphasize the adaptability of the cognitive system to the demands made by different languages during reading, and also the enduring effects of language experience, showing that participants utilize strategies that work in all of their languages. It is clear that these hypotheses must be tested with additional languages which differ in principled ways that can allow us to separate out effects related to the orthography, and effects related to language structure.

Appendix A. Stimuli presented in this experiment.

5 letter complex words		6 letter complex words		5 letter complex nonwords	6 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	Useful 58	Vater	Litful	Pilker
		Bakery 2(36)	Verbal 21		Liping	Unraim
		Beaten 15	Saying 113		Relope	Seaper
		Hatred 20	Heroic 21		Soupen	Operer
		Ironic 13			Unwasp	
	mn freq = 37.02					
Ocean 34	Saint 16	Engine 50	League 69	Abent	Ufgine	Farble
Agent 44	Beard 26	Violin 11	Utopia 24	Doyak	Gealth	Benslo
Dress 67	Mouse 10	Virgin 35	Potato 15	Amale	Wanget	Donkle
Radio 120	Image 119	Motive 22	Poodle 2	Smage	Dittle	Adeast
Idiot 2	Laugh 28	Battle 87	Domain 9	Leard	Udoryp	Iglipe
Apple 9	Issue 152	Advice 52	Dollar 46	Avort	Hamage	Lainth
Lemon 18	Razor 15	Wealth 22	Accent 9	Bemin	umtado	likcen
		Heaven 43	Genius 23	Icrog	Ansoct	Rupait
		Rabbit 11	Sponge 7	Oplep	Liolin	Rafoon
		Legend 26	Screen 48	Idace	Leerus	Desius
		Window 119	Forest 66	Ukint	Wottle	Edoice
		Smooth 42	Lesson 29	Iless	Sichin	Modolt
		Scream 13	Pirate 4	Mooth	Serble	Sabbit
					Baream	
	mn Freq = 38.6					

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