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Morphological processing during visual word recognition in Hebrew as a first and a second language

Tal Norman[1] · Tamar Degani[2] · Orna Peleg[3]

Abstract The present study examined whether sublexical morphological processing takes place during visual word-recognition in Hebrew, and whether morphological decomposition of written words depends on lexical activation of the complete word. Furthermore, it examined whether morphological processing is similar when reading Hebrew as a first language (L1) or as a second language (L2), and whether L1's morphological background, Semitic or Indo-European, modulates morphological processing in L2 Hebrew (a Semitic language), among proficient readers. To reveal the sublexical processing of the Hebrew morphemes, the Root (R) and the Pattern (P), a lexical-decision task was conducted, in which all critical stimuli were non-word letter-strings manipulated to include or exclude real Hebrew morphemes. Different combinations of real (+) and pseudo (−) morphemes yielded four types of non-words (+R+P; +R−P; −R+P, −R−P). Three groups of proficient Hebrew readers were tested: L1 Hebrew, L1 English-L2 Hebrew, and L1 Arabic-L2 Hebrew. Results demonstrated significant differences in latency and accuracy of responses to the four morphological conditions, indicating that sublexical morphological processing occurs during visual word-recognition of morphologically structured letter-strings in Hebrew. Importantly, the activation of real Hebrew morphemes occurred in non-word stimuli, indicating that morphological processing in Hebrew is separable from lexical activation. Moreover, the same pattern of results was observed in all three L1 groups, indicating that proficient L2 readers exhibit morphological processing strategies that are tuned to the L2 morphology, regardless of their L1 background.

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Introduction

A large number of words in Semitic as well as in Indo-European languages are morphologically complex in that they contain more than one morpheme. The purpose of the present study was to examine the extent to which sublexical morphological analysis in such words occurs during visual word-recognition in Hebrew, as a first language (L1) and as a second language (L2).

The particular morphological structure of a given language modulates the way it is processed (e.g., Bick, Goelman, & Frost, 2011). For instance, Indo-European languages, such as English, have a linear and relatively simple morphological system in which morphologically complex words are formed by connecting morphological units (e.g., *-ness*) to a stem morpheme (e.g., *dark*) in a linear manner (e.g., *darkness*). Therefore, readers of Indo-European languages are generally insensitive to the internal ordering of letters within the word (e.g., Perea & Lupker, 2003), except for morphological boundaries of derived and compound words (e.g., Creistianson, Johnson, & Rayner, 2005 but see Rueckl & Rimzhim, 2011). In contrast, Semitic languages have a richer and more complex morphological system in which two kinds of morphemes, the Root and the Pattern, are superimposed upon each other in a non-linear manner. For example, the Root *K.L.D* and the Pattern *miCCeCet* are intertwined to create the Hebrew word *miKLeDet* (keyboard). These two morphemes cannot stand alone as independent words (e.g., Bar-On & Ravid, 2011). Therefore, readers of Semitic languages are highly sensitive to the internal morphological structure of words (e.g., Velan & Frost, 2011).

Our first aim was to determine whether during L1 reading of Hebrew, morphological processing occurs even before the complete word is recognized or whether it depends on lexical access. Therefore, a lexical-decision task was conducted, in which all critical stimuli were non-words, manipulated to include or exclude two Hebrew morphemes, the Root (R) and the Pattern (P). Different combinations of real (+) and pseudo (−) morphemes yielded four types of non-words (+R+P; +R−P; −R+P, −R−P). If Hebrew morphemes are recognized in the absence of lexical representation, as in the case of non-words, then the presence of morphemes in non-words will hinder performance.

Our second aim was to examine whether sublexical morphological processing also occurs during L2 reading of Hebrew. Differences between L1 and L2 readers may emerge because morphological-processing abilities are correlated with reading skills in L1 (e.g., Bar-On & Ravid, 2011) and in L2 (e.g., Jeon & Yamashita, 2014). Further, it has recently been demonstrated that L1's morphological background modulates morphological processing during L2 reading among *beginning* L2 learners of Hebrew (Norman, Degani, & Peleg, 2016). In the present study, we focused on *proficient* L2 readers of Hebrew, and our third aim was to examine whether the morphological characteristics of the L1, Indo-European (English) or Semitic (Arabic), modulate morphological processing during L2 reading of a

Semitic language (Hebrew), among *proficient* L2 readers. Therefore, three groups of proficient Hebrew readers were tested: L1 Hebrew, L1 English-L2 Hebrew, and L1 Arabic-L2 Hebrew. Notably, both English and Arabic use orthographic systems that are distinct from that of Hebrew.

Morphological processing during visual word-recognition in a first language

According to interactive views, higher-order linguistic representations modulate early orthographic processing (Carreiras, Armstrong, Perea, & Frost, 2014). Thus, visual word-recognition is assumed to be modulated by the phonological, morphological and semantic features of a given language and a given writing system (Frost, 2012). It is generally agreed that morphological processing occurs while reading morphologically complex words, but it is still debated whether this kind of processing occurs *before* (Taft & Forster, 1975) or *after* (Giraudo & Grainger, 2001) activation of the full lexical representation. The supra-lexical view of morphological processing assumes no representation and no activation of separate morphological units. Thus, morphological processing is hypothesized to occur *after* lexical activation of the complete word, and should not take place while reading morphologically constructed non-words or unfamiliar new words, which do not have lexical representations (Giraudo & Grainger, 2001). Conversely, the sublexical view of morphological processing assumes that morphological units are represented separately in the mental lexicon, and are processed *before* the activation of the complete lexical representation. Morphological decomposition is applied to all morphologically constructed stimuli, irrespective of their lexical status. Accordingly, non-words composed of legal combination of existing morphemes in a given language, are morphologically decomposed (Taft & Forster, 1975).

In Indo-European languages, it has been demonstrated that the reading process of morphologically complex words involves rapid decomposition of a word into its constituent morphemes (Amenta & Crepaldi, 2012; Rastle & Davis, 2008). For instance, morphologically simple target words (e.g., *sport*) are primed by morphologically structured *real-words* (e.g., *sportive-sport*) as well as by morphologically structured *non-words* (e.g., *sportation-sport*) (Longtin, Segui, & Halle, 2003), supporting the claim that mandatory morpho-orthographic parsing takes place at an early phase of visual word-recognition in Indo-European languages (Frost, Grainger, & Carreiras, 2008).

In Semitic languages, morphological decomposition was demonstrated mainly during the processing of *real-words*. Priming effects were found for morphologically related word-pairs, in both Hebrew and Arabic (e.g., Frost, Kugler, Deutsch, & Forster, 2005). Further, eye-movement studies of sentence reading suggest that Hebrew readers can extract morphological information from unfixated words perceived in the parafovea, such that parafoveal preview-words derived from the same Root (Deutsch, Frost, Pelleg, Pollatsek, & Rayner, 2003) or Pattern (Deutsch, Frost, Pollatsek, & Rayner, 2005) as the foveal target word facilitate lexical processing of the target.

Importantly, existing evidence regarding the processing of morphologically constructed *non-words* in Semitic languages is insufficient. In one eye-movement study of sentence reading in Hebrew, readers differentiated between non-words with real Root and Pattern, and non-words with real Patten and pseudo Root, already in the early phases of word reading (Velan, Deutsch, & Frost, 2013). To further explore sublexical morphological processing of the Root and the Pattern, both separately and conjointly, the present study used a lexical-decision task with four types of morphologically constructed *non-word* stimuli.

Morphological processing during visual word recognition in a second language

L2 learners as well as bilinguals are required to activate, monitor and use two or more sets of linguistic knowledge and linguistic processing strategies. According to interactive views, both languages are simultaneously active (Dijkstra, 2005) and thus, linguistic features from L1 frequently transfer and appear during the use of L2. Such L1-transfer can negatively influence L2 processing when linguistic features of the two languages are different and implementation of L1's features during L2 use results in erroneous linguistic outcome (MacWhinney, 2005).

L1-transfer has been shown to affect orthographic (Miller, 2011) phonological (Wang, Koda, & Perfetti, 2003) and morphological (Pasquarella, Chen, Lam, & Luo, 2011; Schiff & Calif, 2007) aspects of visual word-recognition processes in L2. Morphological transfer from L1 to L2 is hypothesized to occur in terms of the underlying functions expressed by morphological features, and not in terms of the exact morphological forms (MacWhinney, 2005). The pattern of L1 transfer appears to differ as a function of the similarity of the morphological features in the two languages (Pasquarella et al., 2011; Schiff & Calif, 2007) and as a function of L2 proficiency level (Liang & Chen, 2014). For instance, knowledge regarding derivational morphology transfers between two alphabetic languages that are rich in derivational linear word structure (Schiff & Calif, 2007), whereas knowledge regarding compound morphology transfers between two languages with compound word structures (Pasquarella et al., 2011). Liang and Chen (2014) found that highly proficient L2 learners were more sensitive to the morphological structure of the L2 word than were less proficient L2 learners.

In the case of morphological processing during L2 reading, L2 readers may transfer and use the same morphological processing strategies they use in their L1 (Norman et al., 2016). Alternatively, they may use the same morphological strategies as native readers do (Dipendaele, Dunabeitia, Morris, & Keuleers, 2011), such that L2 reading strategies are modulated by L2 specific morphological characteristics, and are not subjected to L1-transfer. A third possibility is that L2 readers, as opposed to native readers, rely more on whole-word lexical activation and less on morphological decomposition, during visual word-recognition (Silva & Clahsen, 2008).

L1-transfer of morphological processing strategies was demonstrated among beginning L2 learners of Hebrew, whose L1 was either a Semitic (Arabic) or an

Indo-European (English) language (Norman et al., 2016). In that study, beginning L2 Hebrew learners completed an off-line graded lexical-decision task on unfamiliar letter strings in Hebrew. Critically, these were manipulated to include (+) or exclude (−) familiar real Hebrew morphemes yielding four conditions (+R +P, +R−P, −R+P, −R−P). The presence or absence of familiar and real morphemes differentially affected lexical decisions in the two L1 groups of learners. Beginning learners whose L1 is Indo-European exhibited increased sensitivity to Pattern familiarity with little effect of Root familiarity, such that a familiar Pattern lead to a word response and an unfamiliar Pattern lead to a non-word response, irrespective of Root familiarity. In contrast, beginning learners whose L1 is Semitic exhibited non-additive sensitivity to the joint combination of both familiar morphemes. Only letter strings with both a familiar Root and a familiar Pattern were judged as real Hebrew words. These findings suggest that both groups of L2 learners activated some kind of morphological knowledge in order to process unfamiliar L2 Hebrew words. However, the morphological knowledge that was activated, and the processing strategy that was implemented, were modulated by L1's morphological characteristics (intertwined Semitic morphology or linear Indo-European morphology).

In contrast, similar processing strategies of morphologically complex words were demonstrated among L1 readers and proficient L2 readers of English, suggesting that it is the morphological characteristics of the L2 itself that determine how written L2 words are being processed (Dipendaele et al., 2011). Yet, other findings suggest that L1 readers rely fully on morphologically structured representations when reading morphologically complex words, whereas L2 readers rely to a much lesser degree on morphological analysis (Silva & Clahsen, 2008). Further, sensitivity to the words' morphological structure may develop with L2 proficiency (Liang & Chen, 2014).

In sum, previous research provided inconsistent evidence regarding the nature of morphological processing in *proficient* L2 readers (Dipendaele et al., 2011; Liang & Chen, 2014; Silva & Clahsen, 2008). Here we aim to determine the nature of sublexical morphological processing among *proficient* L2 readers of Hebrew.

The present study

To investigate these issues, L1 Hebrew readers, and proficient L2 readers of Hebrew whose L1 was either Arabic or English, performed a lexical-decision task, in which Hebrew letter strings were manipulated to include or exclude real Root and Pattern morphemes. All critical stimuli were non-words that could include two real morphemes, the Root and the Pattern, one real morpheme, either the Root or the Pattern, or none. If morphemes are recognized independent of lexical access, then non-words with real morphemes will be more difficult to reject in a lexical-decision task, compared to non-words with no real morphemes. Furthermore, non-words, consisting of two real morphemes, may be more difficult to reject, compared to non-words consisting of only one real morpheme. On the other hand, if morphological processing occurs after the complete word is recognized, then no differences are expected in processing non-words with two real morphemes, one real morpheme, or none, because all are non-words that could not be recognized as a whole. Finally, if L1-transfer occurs among proficient L2 readers of Hebrew, we expect the L1 Arabic group to be more sensitive to internal Semitic morphological information. They will thus recognize and activate knowledge regarding real Root and Pattern morphemes to a greater extent than the L1 English group, due to the similar morphological word structure in all Semitic languages, and due to the central role for the Root morpheme during lexical access in both Hebrew and Arabic (Frost et al., 2005).

Method

Participants

Sixty-three adults participated in this experiment. Of these, 21 were native speakers of Hebrew who were not native speakers of any other language, all reporting Hebrew as the only language spoken at home. Twenty-one were proficient L2 readers of Hebrew whose L1 was English, and 21 were proficient L2 readers of Hebrew whose L1 was Arabic. All participants reported that their first language (Hebrew-first group, English-second group, and Arabic-third group) was their only native language, and that they had not been exposed to other languages at home before age six.

Critically, participants in the second (L1-English) and third (L1-Arabic) groups reported learning to read Hebrew *after* learning to read in their native language.[1] Furthermore, participants in these groups were required to complete a detailed language-history and self-rating questionnaire regarding their L1 and L2 background and knowledge, modified from LEAP Q (Marian, Blumenfeld, & Kaushanskaya, 2007). Accordingly, participants in the two L2-Hebrew groups rated themselves as highly proficient readers of Hebrew. Importantly, these ratings did not differ significantly between the two groups based on a one-way ANOVA test with the Bonferroni corrections for multiple comparisons. Given that the focus of the present study was on visual word recognition, this was the most important criterion for matching between the two L2-Hebrew groups. In addition, these two groups did not differ statistically in overall-performance in the experimental lexical decision task (i.e., accuracy rates and latency scores), based on a one-way ANOVA test with the Bonferroni corrections for multiple comparisons (L1-English: 93.65 % SD 4.98, 1271.5 ms SD 367.7; L1-Arabic: 91.31 % SD 4.76, 1088.1 ms SD 340.9).

Participants in all three groups live in Israel, participated in the experiment for payment, and reported normal or corrected to normal vision. For detailed characteristics of participants by L1 groups, see Table 1.

[1] Four participants from the L1-English group reported that they learned to read Hebrew while they were learning to read in their native language English. However, they learned to read biblical Hebrew using the pointed writing system, which is different from the non-pointed writing system that is used for reading Modern Hebrew and was used in the current experiment. In addition, all of them reported that their reading in English is much better than their reading in Hebrew.

Table 1 Participants' background characteristics and baseline performance—means (SD) by L1 group*

Measure	L1 Group		
	English	Arabic	Hebrew
Number and gender	21 (8 males)	21 (4 males)	21 (9 males)
Age	39.43 (13.33)$_a$	24.19 (3.71)$_b$	26.81 (3.74)$_b$
Lexical decision accuracy**	93.65 % (4.98)$_a$	91.31 % (4.76)$_a$	97.06 % (1.75)$_b$
Lexical decision latency**	1271.5 ms (367.7)$_a$	1088.1 ms (340.9)$_a$	693.0 ms (91.6)$_b$
Age began study L2	7.05 (1.86)$_a$	8.76 (3.19)$_a$	N/A
Years studied L2	9.05 (4.27)$_a$	10.24 (2.09)$_a$	N/A
Current exposure to L1	54.29 % (20.93)$_a$	50.00 % (17.82)$_a$	N/A
Current exposure to L2	44.95 % (21.17)$_a$	40.95 % (18.95)$_a$	N/A
Current use of L1 (0–10 scale)***	7.33 (1.46)$_a$	6.29 (1.42)$_b$	N/A
Current use of L2 (0–10 scale)***	5.71 (2.05)$_a$	6.10 (1.48)$_a$	N/A
L1 proficiency (0–10 scale)****	9.95 (.22)$_a$	9.82 (.50)$_a$	N/A
L2 proficiency (0–10 scale)****	7.93 (1.36)$_a$	8.73 (.88)$_b$	N/A
L1 reading proficiency (0–10 scale)	9.90 (.44)$_a$	9.76 (1.10)$_a$	N/A
L2 reading proficiency (0–10 scale)	8.00 (1.73)$_a$	8.86 (1.10)$_a$	N/A
L1 Reading preference	78.33 % (28.78)$_a$	46.90 % (32.73)$_b$	N/A
L2 Reading preference	21.67 % (28.78)$_a$	40.71 % (34.50)$_a$	N/A
L1 current use—reading (0–10 scale)	8.29 (1.82)$_a$	6.52 (2.18)$_b$	N/A
L2 current use—reading (0–10 scale)	5.24 (2.88)$_a$	8.00 (1.79)$_b$	N/A

* Means in the same row that do not share sub-scripts differ at the $p < .05$ level in a one-way ANOVA test with the Bonferroni corrections for multiple comparisons

** Accuracy (percentage) and Latency (ms) measures are the mean results from the experimental lexical decision task. Self-rated information is based on a modified version of the LEAP-Q language history questionnaire (Marian et al., 2007)

*** Current Use scores are the average of speaking, writing, reading, listening (radio), and watching TV ratings

**** Proficiency scores are the average of reading, writing, conversational, and speech-comprehension ability ratings

Stimuli

Stimuli consisted of 240 Hebrew letter strings including 120 experimental items and 120 fillers. All items were 5–6 letters long ($M = 5.4$). All fillers were real Hebrew words (nouns and verbs) with Semitic morphological structure consisting of a Root and a Pattern. All experimental items were non-words manipulated to create different morphological conditions. Four conditions with 30 items each were created by orthogonally manipulating the existence of real (+) and pseudo (−) Root (R) and Pattern (P) morphemes within the letter-strings. For condition structure, see Table 2. The conditions were as follows: (1) The +R+P condition consisted of non-words constructed of real-Roots and real-Patterns. (2) The +R−P condition consisted of non-words constructed of real-Roots intertwined with pseudo-Patterns. (3) The −R +P condition consisted of non-words constructed of pseudo-Roots intertwined with real-Patterns. (4) The −R−P condition consisted of non-words with pseudo-Roots

Table 2 Condition structure

Condition	Real root (+R)	Pseudo root (−R)
Real word-pattern (+P)	+R+P	−R+P
Pseudo word-pattern (−P)	+R−P	−R−P

and pseudo-Patterns. Examples of stimuli in each experimental condition are presented in Table 3.

Procedure

Participants were told that they would see a series of letter-strings on the screen and were instructed to classify each as a real Hebrew word or as a non-existing Hebrew word. They were asked to do so as quickly but as accurately as possible by pressing a 'yes' or 'no' button with the pointing finger of the dominant hand. Each participant was presented with a different random order of the 240 items, preceded by the same 10 practice items (five real words and five non-words). Ten blocks of 24 trials each were separated by short breaks. Stimuli were presented centered on the computer screen in black letters on a white background, in Times New Roman Hebrew font, in size 30. Each trial began with a fixation cross at the center of the computer screen (for 500 ms), followed by the letter string until a response was made. Auditory feedback, provided for incorrect responses only, was presented during an inter-trial interval of 1.5 s. During practice, a visual feedback for correct and incorrect responses was also provided. Response accuracy and latency (RTs) were recorded by the E-Prime software (Psychology Software Tools, Pittsburgh, PA, USA). At the end of this task, participants who were L2 readers of Hebrew (i.e., L1 English and L1 Arabic speakers) completed a self-rating questionnaire regarding their L1 and L2 background and knowledge.

Results

For the analysis by participants (reported as F_1), mean RT and accuracy rates were subjected to a 2 × 2 × 3 repeated measures ANOVA with two fully crossed within-participant factors of *Root Status* (*Real* vs. *Pseudo*) and *Pattern Status* (*Real* vs. *Pseudo*) and one between-participant factor of *L*1 *Group* (*Hebrew* vs. *English* vs. *Arabic*). Conversely, for the analysis by items (reported as F_2), mean RT and accuracy rates were computed for each item in each L1 group and were subjected to a 3 × 2 × 2 repeated measures ANOVA, such that *L*1 *Group* was treated as a within-item factor and *Root Status* and *Pattern Status* were treated as between-item factors.

RT results

Responses over 5000 ms were excluded as cutoff (.2 %), and RTs more than 2.5 standard deviations (*SDs*) from the participant's mean for correct responses were

Table 3 Example stimuli and results in each condition by L1 group

			(1) +R+P	(2) +R−P	(3) −R+P	(4) −R−P
Examples						
Hebrew			תרקודת	תותרקד	תרשוגת	תותרשג
Orthographic transliteration			tRKoDt	totRKD	tRʃoGt	totRʃG
Root			R.K.D	R.K.D	R.ʃ.G*	R.ʃ.G*
Word-pattern			tCCoCt	totCCC*	tCCoCt	totCCC*
*Results***						
(1) Hebrew	RT	F_1	820.37 $(124.82)_a$	674.67 $(86.49)_b$	713.59 $(99.64)_c$	654.98 $(80.42)_d$
		F_2	880.53 $(72.53)_a$	684.60 $(29.90)_b$	726.33 $(76.15)_c$	657.00 $(28.34)_b$
	Acc	F_1	84.92 $(10.57)_a$	99.84 $(.73)_b$	99.84 $(.73)_b$	99.84 $(.73)_b$
		F_2	84.92 $(16.50)_a$	99.84 $(.87)_b$	99.84 $(.87)_b$	99.84 $(.87)_b$
(2) English	RT	F_1	1625.81 $(552.88)_a$	1369.12 $(474.64)_b$	1376.48 $(443.25)_b$	1254.28 $(422.19)_c$
		F_2	1893.30 $(269.31)_a$	1429.33 $(266.00)_b$	1474.17 $(304.84)_b$	1295.67 $(198.00)_b$
	Acc	F_1	73.49 $(17.72)_a$	97.62 $(5.59)_{b,c}$	96.67 $(5.58)_b$	99.05 $(1.87)_c$
		F_2	73.49 $(17.18)_a$	97.62 $(3.25)_b$	96.67 $(4.70)_b$	99.05 $(2.62)_b$
(3) Arabic	RT	F_1	1283.81 $(413.08)_a$	1124.94 $(377.63)_b$	1137.91 $(332.11)_b$	1030.40 $(354.56)_c$
		F_2	1422.70 $(144.33)_a$	1168.07 $(143.68)_b$	1198.07 $(170.41)_b$	1033.17 $(93.70)_c$
	Acc	F_1	61.27 $(22.67)_a$	98.41 $(2.91)_b$	94.29 $(6.92)_c$	99.21 $(1.80)_b$
		F_2	61.27 $(19.48)_a$	98.41 $(2.60)_b$	94.29 $(7.12)_b$	99.21 $(1.80)_b$

* Pseudo-morphemes. The C letters mark the empty slots within the Word-Pattern for the consonantal Root letters

** Means in the same row that do not share an alphabetic subscript differ at the $p < .05$ level based on planned paired *t* tests between conditions. Standard deviations (SDs) are shown in parenthesis. *RTs* (ms) are presented in the two upper rows for each L1 group. *Accuracy Rates* (%) are presented in the two lower rows for each L1 group. *Results by participants* (F_1) are presented above the *Results by items* (F_2) for each type of measure

truncated (3.4 %). The RT data show a significant main effect of *L*1 *Group*, *Root Status* and *Pattern Status*: *L*1 *Group*—$F_1(2,60) = 21.368$, $MSE = 477{,}665.956$, $p < .001$, $\eta p^2 = .416$; $F_2(2,232) = 916.057$, $MSE = 20{,}480.375$, $p < .001$, $\eta p^2 = .888$. *Root Status*—$F_1(1,60) = 161.886$, $MSE = 5777.903$, $p < .001$, $\eta p^2 = .730$; $F_2(1,116) = 58.792$, $MSE = 50{,}905.572$, $p < .001$, $\eta p^2 = 336$. *Patten Status*—$F_1(1,60) = 143.072$, $MSE = 8828.928$, $p < .001$, $\eta p^2 = .705$; $F_2(1,116) = 86.515$, $MSE = 50{,}905.572$, $p < .001$, $\eta p^2 = .427$.

The two-way interaction between *Root Status* and *L*1 *Group* was significant, $F_1(2,60) = 12.843$, $MSE = 5777.903$, $p < .001$, $\eta p^2 = .300$; $F_2(2,232) = 12.609$, $MSE = 20{,}480.375$, $p < .001$, $\eta p^2 = .098$, as was the two-way interaction between *Pattern Status* and *L*1 *Group*, $F_1(2,60) = 4.657$, $MSE = 8828.928$, $p = .013$,

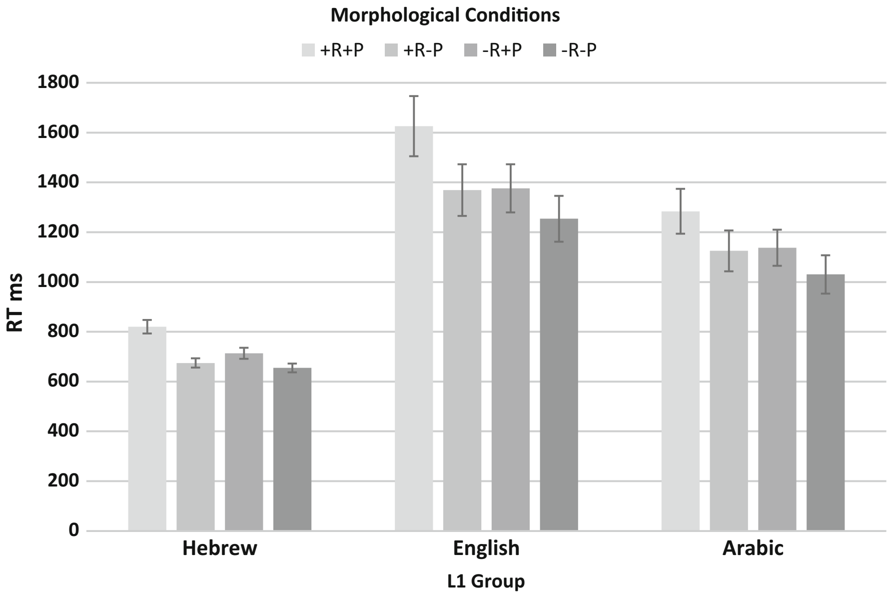

Fig. 1 Mean RTs by subjects for each L1 group in the four morphological conditions. *Error bars* represent SE

$\eta p^2 = .134$; $F_2(2,232) = 13.170$, $MSE = 20{,}480.375$, $p < .001$, $\eta p^2 = .102$. The two-way interaction between *Root Status* and *Pattern Status* was significant as well, $F_1(1,60) = 22.273$, $MSE = 5853.232$, $p < .001$, $\eta p^2 = .271$; $F_2(1,116) = 12.366$, $MSE = 50{,}905.572$, $p = .001$, $\eta p^2 = .096$. Importantly, the three-way interaction between *Root Status*, *Pattern Status* and *L1 Group* was significant by items, $F_1(2,60) = 1.559$, $MSE = 5853.232$, $p = .219$, $\eta p^2 = .049$; $F_2(2,232) = 3.962$, $MSE = 20{,}480.375$, $p = .020$, $\eta p^2 = .033$.

To examine the source of this three-way interaction, the effects of the two morphemes were examined for each L1 group separately. For the L1 Hebrew group, the results show a significant main effect of *Root Status*, $F_1(1,20) = 170.971$, $MSE = 491.151$, $p < .001$, $\eta p^2 = .895$; $F_2(1,116) = 77.728$, $MSE = 3189.132$, $p < .001$, $\eta p^2 = .401$, and of *Pattern Status*, $F_1(1,20) = 157.441$, $MSE = 1391.985$, $p < .001$, $\eta p^2 = .887$; $F_2(1,116) = 165.483$, $MSE = 3189.132$, $p < .001$, $\eta p^2 = .588$. The interaction between them was significant as well, $F_1(1,20) = 46.963$, $MSE = 847.905$, $p < .001$, $\eta p^2 = .701$; $F_2(1,116) = 37.693$, $MSE = 3189.132$, $p < .001$, $\eta p^2 = .245$. Planned paired t-tests show that all conditions differed from each other ($p < .002$), such that response latencies were the slowest in the +R+P condition. They were faster in the −R+P condition and even faster in the +R−P condition. Finally, response latencies were the fastest in the −R−P condition. See Fig. 1 and Table 4 for details.

Table 4 Statistical data for the analysis by participants*

	L1-group	Root	Pattern
Over-all effects			
Main effects			
RT	$F_1(2,60) = 21.368$, $p < .001$	$F_1(1,60) = 161.886$, $p < .001$	$F_1(1,60) = 143.072$, $p < .001$
ACC	$F_1(2,60) = 8.423$, $p = .001$	$F_1(1,60) = 138.780$, $p < .001$	$F_1(1,60) = 141.580$, $p < .001$
Two-way interactions	L1-group by root	L1-group by pattern	Root by pattern
RT	$F_1(2,60) = 12.843$, $p < .001$	$F_1(2,60) = 4.657$, $p = .013$	$F_1(1,60) = 22.273$, $p < .001$
ACC	$F_1(2,60) = 6.907$, $p = .002$	$F_1(2,60) = 11.302$, $p < .001$	$F_1(1,60) = 171.638$, $p < .001$
Three-way interaction	L1-group by root by pattern		
RT	$F_1(2,60) = 1.559$, $p = .219$		
ACC	$F_1(2,60) = 8.240$, $p = .00$		

	Root	Pattern
Effects for each L1-group separately		
L1-Hebrew		
Main effects		
RT	$F_1(1,20) = 170.971$, $p < .001$	$F_1(1,20) = 157.441$, $p < .001$
ACC	$F_1(1,20) = 44.469$, $p < .001$	$F_1(1,20) = 37.362$, $p < .001$
Two-way interaction	Root by pattern	
RT	$F_1(1,20) = 46.963$, $p < .001$	
ACC	$F_1(1,20) = 44.469$, $p < .001$	
L1-English		
Main effects		
RT	$F_1(1,20) = 70.040$, $p < .001$	$F_1(1,20) = 46.660$, $p < .001$
ACC	$F_1(1,20) = 43.587$, $p < .001$	$F_1(1,20) = 1.781$, $p < .001$
Two-way interaction	Root by pattern	
RT	$F_1(1,20) = 8.881$, p = .007	
ACC	$F_1(1,20) = 70.000$, p < .001	
L1-Arabic		
Main effects		
RT	$F_1(1,20) = 43.979$, $p < .001$	$F_1(1,20) = 41.664$, $p < .001$
ACC	$F_1(1,20) = 57.568$, $p < .001$	$F_1(1,20) = 59.558$, $p < .001$
Two-way interaction	Root by pattern	
RT	$F_1(1,20) = 2.301$, $p = .145$**	
ACC	$F_1(1,20) = 70.000$, $p < .001$	

Error bars represent SE

* The analysis by items (F_2) was significant ($p < .05$), unless noted otherwise

** $F_2(1,116) = 3.046$, $p = .084$

For the L1 English group, there was a significant main effect of *Root Status*, $F_1(1,20) = 70.040$, $MSE = 9941.232$, $p < .001$, $\eta p^2 = .778$; $F_2(1,116) = 33.287$, $MSE = 68{,}853.636$, $p < .001$, $\eta p^2 = .223$, and of *Pattern Status*, $F_1(1,20) = 46.660$, $MSE = 16{,}153.186$, $p < .001$, $\eta p^2 = .700$; $F_2(1,116) = 44.961$, $MSE = 68{,}853.636$, $p < .001$, $\eta p^2 = .279$. The interaction between them was also significant, $F_1(1,20) = 8.881$, $MSE = 10{,}690.954$, $p = .007$, $\eta p^2 = .308$; $F_2(1,116) = 8.877$, $MSE = 68{,}853.636$, $p = .004$, $\eta p^2 = .071$. Planned paired t-tests show that all conditions differed from each other ($p < .001$), except for the +R−P and the −R+P conditions ($p = .778$), such that response latencies were the slowest in the +R+P condition, they were faster in the +R−P and the −R+P conditions, and were the fastest in the −R−P condition.

For the L1 Arabic group, there was a significant main effect of *Root Status*, $F_1(1,20) = 43.979$, $MSE = 6901.326$, $p < .001$, $\eta p^2 = .687$; $F_2(1,116) = 48.906$, $MSE = 19{,}823.553$, $p < .001$, $\eta p^2 = .297$, and of *Pattern Status*, $F_1(1,20) = 41.664$, $MSE = 8941.613$, $p < .001$, $\eta p^2 = .676$; $F_2(1,116) = 66.591$, $MSE = 19{,}823.553$, $p < .001$, $\eta p^2 = .365$. However, the interaction between them was not significant, $F_1(1,20) = 2.301$, $MSE = 6020.836$, $p = .145$, $\eta p^2 = .103$; $F_2(1,116) = 3.046$, $MSE = 19{,}823.553$, $p = .084$, $\eta p^2 = .026$. Planned paired *t* tests show that all conditions differed from each other ($p < .001$), except for the +R−P and the −R+P conditions ($p = .594$), such that response latencies were the slowest in the +R+P condition, they were faster in the +R−P and the −R+P conditions, and were the fastest in the −R−P condition.

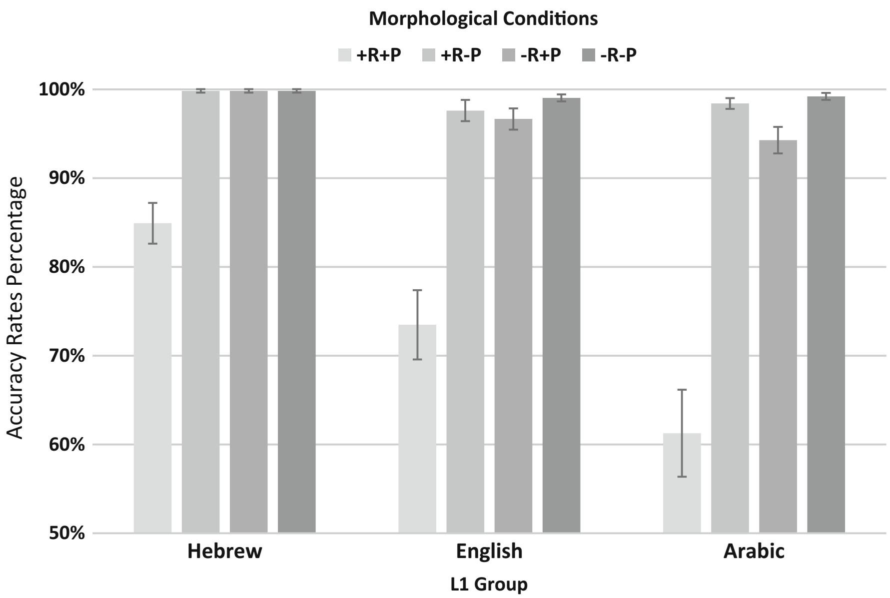

Fig. 2 Mean accuracy rates by subjects for each L1 group in the four morphological condition. *Error bars* represent SE

Accuracy results

For the accuracy measure, the results show a significant main effect of *L1 Group*, *Root Status, and Pattern Status*: *L1 Group*—$F_1(2,60) = 8.423$, $MSE = .015$, $p = .001$, $\eta p^2 = .219$; $F_2(2,232) = 46.664$, $MSE = .004$, $p < .001$, $\eta p^2 = .287$. *Root Status*—$F_1(1,60) = 138.780$, $MSE = .007$, $p < .001$, $\eta p^2 = .698$; $F_2(1,116) = 73.322$, $MSE = .018$, $p < .001$, $\eta p^2 = .387$. *Pattern Status*—$F_1(1,60) = 141.580$, $MSE = .009$, $p < .001$, $\eta p^2 = .702$; $F_2(1,116) = 95.044$, $MSE = .018$, $p < .001$, $\eta p^2 = .450$.

The two-way interaction between *Root Status* and *L1 Group* was significant $F_1(2,60) = 6.907$, $MSE = .007$, $p = .002$, $\eta p^2 = .187$; $F_2(2,232) = 16.940$, $MSE = .004$, $p < .001$, $\eta p^2 = .127$, as were the two-way interactions between *Pattern Status* and *L1 Group* $F_1(2,60) = 11.302$, $MSE = .009$, $p < .001$, $\eta p^2 = .274$; $F_2(2,232) = 35.221$, $MSE = .004$, $p < .001$, $\eta p^2 = .233$, and between *Root Status* and *Pattern Status* $F_1(1,60) = 171.638$, $MSE = .005$, $p < .001$, $\eta p^2 = .741$; $F_2(1,116) = 64.704$, $MSE = .018$, $p < .001$, $\eta p^2 = .358$. Critically, there was a significant three-way interaction between *Root Status*, *Pattern Status*, and *L1 Group*, $F_1(2,60) = 8.240$, $MSE = .005$, $p = .001$, $\eta p^2 = .215$; $F_2(2,232) = 14.420$, $MSE = .004$, $p < .001$, $\eta p^2 = .111$.

To examine the source of this three-way interaction, the effects of the two morphemes were examined for each L1 group separately. For the L1 Hebrew group, there was a significant main effect of *Root Status*, $F_1(1,20) = 44.469$, $MSE = .003$, $p < .001$, $\eta p^2 = .690$; $F_2(1,116) = 24.330$, $MSE = .007$, $p < .001$, $\eta p^2 = .173$, and of *Pattern Status*, $F_1(1,20) = 37.362$, $MSE = .003$, $p < .001$, $\eta p^2 = .651$; $F_2(1,116) = 24.330$, $MSE = .007$, $p < .001$, $\eta p^2 = .173$. The interaction between them was significant as well, $F_1(1,20) = 44.469$, $MSE = .003$, $p < .001$, $\eta p^2 = .690$; $F_2(1,116) = 24.330$, $MSE = .007$, $p < .001$, $\eta p^2 = .173$. Planned paired t-tests showed that only the +R+P condition significantly differed from all other conditions ($p < .001$). Accuracy rates in this group do not present any differences between the +R−P, −R+P, and −R−P conditions, probably due to a ceiling effect, making the accuracy of the L1 Hebrew group a less sensitive measure than the RT measure. See Fig. 2 and Table 4 for details.

For the L1 English group, there was a significant main effect of *Root Status*, $F_1(1,20) = 43.587$, $MSE = .007$, $p < .001$, $\eta p^2 = .685$; $F_2(1,116) = 54.266$, $MSE = .008$, $p < .001$, $\eta p^2 = .319$, and of *Pattern Status*, $F_1(1,20) = 1.781$, $MSE = .007$, $p < .001$, $\eta p^2 = .749$; $F_2(1,116) = 62.994$, $MSE = .008$, $p < .001$, $\eta p^2 = .352$. The interaction between them was significant as well, $F_1(1,20) = 70.000$, $MSE = .008$, $p < .001$, $\eta p^2 = .721$; $F_2(1,116) = 42.394$, $MSE = .008$, $p < .001$, $\eta p^2 = .268$. Planned paired *t* tests show that all conditions differed from each other ($p < .048$), except for the +R−P and −R+P conditions ($p = .186$), and the +R−P and −R−P condition ($p = .215$). L2 Hebrew readers whose L1 is English were the least accurate when two real morphemes were presented, in the +R+P condition. They were more accurate when only one morpheme was presented, in the −R+P or the +R−P conditions, or when no real morphemes were presented, in the −R−P condition.

Finally, for the L1 Arabic group, there was a significant main effect of *Root Status*, $F_1(1,20) = 57.568$, $MSE = .010$, $p < .001$, $\eta p^2 = .742$; $F_2(1,116) = 77.884$,

$MSE = .011$, $p < .001$, $\eta p^2 = .402$, and of *Pattern Status*, $F_1(1,20) = 59.558$, $MSE = .016$, $p < .001$, $\eta p^2 = .749$; $F_2(1,116) = 120.554$, $MSE = .011$, $p < .001$, $\eta p^2 = .510$. The interaction between them was significant as well, $F_1(1,20) = 70.000$, $MSE = .008$, $p < .001$, $\eta p^2 = .778$; $F_2(1,116) = 70.743$, $MSE = .011$, $p < .001$, $\eta p^2 = .379$. Planned paired *t* tests show that all conditions differed from each other ($p < .002$), except for the +R−P and the −R−P conditions ($p = .261$). L2 Hebrew readers whose L1 is Arabic were the least accurate when two real morphemes were presented, in the +R+P condition. They were more accurate when only real Pattern was presented, in the −R+P condition. Finally, they were the most accurate when only real Root was presented, in the +R−P condition, or when no real morphemes were presented, in the −R−P condition.

Discussion

The present study investigated the impact of the Root and the Pattern morphemes on visual word-recognition among L1 and proficient L2 readers of Hebrew. The first aim was to determine whether sublexical morphological processing occurs during visual word-recognition in L1. Results show that L1 Hebrew readers were significantly affected by the presence of real morphemes within non-word stimuli, as indicated by the slower RTs and the lower accuracy rates, when real Root and Pattern morphemes were presented, separately and conjointly. Because morphologically complex non-words cannot be lexically identified, only sublexical morphological identification can explain the current results. Thus, the fact that morphological sensitivity was found during the processing of non-words, indicates that the activation of morphological knowledge is independent from the activation of lexical representation. The current findings support the view that automatic sublexical morphological processing occurs in the early stages of L1 visual word-recognition, prior to lexical activation, and are consistent with evidence demonstrating sublexical morphological processing during visual identification of morphologically constructed non-words (Taft & Forster, 1975; Longtin et al., 2003; Velan et al., 2013).

The second aim was to determine whether sublexical morphological processing occurs during visual word-recognition among proficient L2 readers of Hebrew. Results demonstrated that L2 Hebrew readers were influenced by the presence of real morphemes in non-word stimuli, confirming that proficient L2 readers, similarly to native readers, morphologically decompose and process Hebrew letter-strings prior to lexical identification. The current results are in line with findings from L2 studies in English, demonstrating morphological processing in L2 readers of English during visual word-identification (Dipendaele et al., 2011; Liang & Chen, 2014), and constrain the hypothesis that proficient L2 readers rely more heavily on whole-word processing in their L2 (Silva & Clahsen, 2008).

The third aim was to examine whether L1's morphology modulates morphological processing in L2 among proficient L2 readers. In contrast to findings from *beginning* L2 learners of Hebrew (Norman et al., 2016), the current results indicate that among *proficient* L2 readers, morphological processing is tuned to L2's morphology and is not modulated by L1's morphological characteristics. Proficient L2 readers of Hebrew exhibit morphological decomposition of written words similar to that of native Hebrew readers, irrespective of their L1 background. This suggests that with high proficiency in L2 reading, learners adopt morphological processing strategies that suite L2's morphology.

Importantly, Hebrew readers were most sensitive to the joint presence of two real morphemes, the Root and the Pattern, within a letter-string. However, they were also sensitive to the presence of each morpheme alone. Interestingly, native Hebrew readers were more sensitive to the presence of a real Pattern alone, than to the presence of a real Root alone. The observed sensitivity to the Pattern morpheme may suggest that it has a central role in visual word-recognition of Semitic Hebrew words. It could be the case that proficient Hebrew readers initially identify a Semitic structured letter-string mainly by the identification of the Pattern. Consequently, in the absence of a Pattern, the extraction of the Root letters and the activation of the Root are hindered. Alternatively, this result may reflect an effect of the task itself, namely that during a lexical-decision task, readers attend to the Pattern first, in order to determine whether the presented letter string is a real word or not. However, in natural reading, where readers assume all words are real, they focus more on the Root during word identification. Questions regarding sublexical morphological processing during natural reading of real words, and regarding the time course of such processing, await future investigation.

Notably, the accuracy data of the Arabic speakers show a difference between the presence of a root only or a word pattern only, in that they were less accurate on letter strings with a real word Pattern than on letter strings with a real Root morpheme. This increased sensitivity to the presence of the word pattern resembles the difference observed for native Hebrew speakers discussed above, which may suggest that because of the typological similarity between Arabic and Hebrew these speakers resemble native Hebrew speakers slightly more than native English speakers (see also Norman et al., 2016). Nevertheless, the *similarity* between the three L1 groups is more apparent in the current findings than differences due to L1 background.

To conclude, in the present study, automatic decomposition and activation of sublexical morphological units, which occurred without whole-word lexical identification, was demonstrated in Semitic structured *non-words*. This finding indicates that morpho-orthographic processing and lexical processing are separate and independent processes. Moreover, no evidence for L1-transfer of morphological processing strategies was found among proficient L2 readers of Hebrew, indicating that the Semitic morphological features of Hebrew modulate the way written Hebrew words are processed by both L1 and proficient L2 readers of Hebrew.

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References

Amenta, S., & Crepaldi, D. (2012). Morphological processing as we know it: An analytical review of morphological effect in visual word identification. *Frontiers in Psychology, 3*, 1–12.

Bar-On, A., & Ravid, D. (2011). Morphological analysis in learning to read pseudowords in Hebrew. *Applied Psycholinguistics, 32*, 553–581.
Bick, A. S., Goelman, G., & Frost, R. (2011). Hebrew Brain vs. English Brain: Language modulates the way it is processed. *Journal of Cognitive Neuroscience, 23*, 2280–2290.
Carreiras, M., Armstrong, B. C., Perea, M., & Frost, R. (2014). The what, when, where and how of visual word recognition. *Trends in Cognitive Sciences, 18*, 90–98.
Creistianson, K., Johnson, R., & Rayner, K. (2005). Letter transpositions within and across morphemes. *Journal of Experimental Psychology. Learning, Memory, and Cognition, 31*(6), 1327–1339.
Deutsch, A., Frost, R., Pelleg, S., Pollatsek, A., & Rayner, K. (2003). Early morphological effects in reading: Evidence from parafoveal preview benefit in Hebrew. *Psychonomic Bulletin and Review, 10*, 415–422.
Deutsch, A., Frost, R., Pollatsek, A., & Rayner, K. (2005). Morphological parafoveal preview benefit effects in reading: Evidence from Hebrew. *Language and Cognitive Processes, 20*, 341–371.
Dijkstra, T. (2005). Bilingual visual word recognition and lexical access. In J. F. Kroll & A. M. B. de Groot (Eds.), *Handbook of bilingualism: Psycholinguistic approaches* (pp. 179–201). New York, NY: Oxford University Press.
Dipendaele, K., Dunabeitia, J. A., Morris, J., & Keuleers, E. (2011). Fast morphological effects in first and second language word recognition. *Journal of Memory and Language, 64*, 344–358.
Frost, R. (2012). Towards a universal model of reading. *Behavioral and Brain Science, 35*, 263–329.
Frost, R., Grainger, J., & Carreiras, M. (2008). Advances in morphological processing: An introduction. *Language and Cognitive Processes, 23*, 933–941.
Frost, R., Kugler, T., Deutsch, A., & Forster, K. I. (2005). Orthographic structure versus morphological structure: Principles of lexical organization in a given language. *Journal of Experimental Psychology. Learning, Memory, and Cognition, 31*, 1293–1326.
Giraudo, H., & Grainger, J. (2001). Priming complex words: Evidence for supralexical representation of morphology. *Psyconomic Bulletin and Review, 8*, 127–131.
Jeon, E. H., & Yamashita, J. (2014). L2 reading comprehension and its correlates: A meta-analysis. *Language Learning, 64*, 160–212.
Liang, L., & Chen, B. (2014). Processing morphologically complex words in second-language learners: The effect of proficiency. *Acta Psychologica, 150*, 69–79.
Longtin, C. M., Segui, J., & Halle, P. A. (2003). Morphological priming without morphological relationship. *Language and Cognitive Processes, 18*, 313–334.
MacWhinney, B. (2005). A unified model of language acquisition. In J. F. Kroll & A. M. B. de Groot (Eds.), *Handbook of bilingualism: Psycholinguistic approaches* (pp. 49–67). New York, NY: Oxford University Press.
Marian, V., Blumenfeld, H. K., & Kaushanskaya, M. (2007). The Language Experience and Proficiency Questionnaire (LEAP-Q): Assessing language profiles in bilinguals and multilinguals. *Journal of Speech, Language, and Hearing Research, 50*, 940–967.
Miller, R. T. (2011). Impact of L2 reading proficiency on L1 transfer in visual word recognition. In G. Granena, et al. (Eds.), *Selected proceedings of the 2010 second language research forum* (Vol. 2617, pp. 78–90). Somerville, MA: Cascadilla Proceedings Project.
Norman, T., Degani, T., & Peleg, O. (2016). Transfer of L1 visual word recognition strategies during early stages of L2 learning: Evidence from Hebrew learners whose first language is either Semitic or Indo-European. *Second Language Research, 32*, 109–122.
Pasquarella, A., Chen, X., Lam, K., & Luo, Y. C. (2011). Cross-language transfer of morphological awareness in Chinese–English bilinguals. *Journal of Research in Reading, 34*, 23–42.
Perea, M., & Lupker, S. J. (2003). Does jugde activate COURT? Transposed-letter similarity effects in masked associative priming. *Memory and Cognition, 31*, 829–841.
Rastle, K., & Davis, M. H. (2008). Morphological decomposition based on the analysis of orthography. *Language and Cognitive Processes, 23*, 942–971.
Rueckl, J. G., & Rimzhim, A. (2011). On the interaction of letter transpositions and morphemic boundaries. *Language and cognitive processes, 26*, 482–508.
Schiff, R., & Calif, S. (2007). Role of phonological and morphological awareness in L2 oral word reading. *Language Learning, 57*, 271–298.
Silva, R., & Clahsen, H. (2008). Morphologically complex words in L1 and L2 processing: Evidence from masked priming experiments in English. *Bilingualism: Language and Cognition, 11*, 245–260.
Taft, M., & Forster, K. (1975). Lexical storage and retrieval of prefixed words. *Journal of Verbal Learning and Verbal Behavior, 14*, 638–647.

Velan, H., Deutsch, A., & Frost, R. (2013). The flexibility of letter-position flexibility: evidence from eye-movments in reading Hebrew. *Journal of Experimental Psychology: Human Perception and Performance, 39*, 1143–1152.

Velan, H., & Frost, R. (2011). Words with and without internal structure: What determines the nature of orthographic and morphological processing? *Cognition, 118*, 141–156.

Wang, M., Koda, K., & Perfetti, C. A. (2003). Alphabetic and nonalphabetic L1 effects in English word identification: a comparison of Korean and Chinese English L2 learners. *Cognition, 87*, 129–149.