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Letter-transposition effects are not universal: The impact of transposing letters in Hebrew

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Abstract

We examined the effects of letter transposition in Hebrew in three masked-priming experiments. Hebrew, like English has an alphabetic orthography where sequential and contiguous letter strings represent phonemes. However, being a Semitic language it has a non-concatenated morphology that is based on root derivations. Experiment 1 showed that transposed-letter (TL) root primes inhibited responses to targets derived from the non-transposed root letters, and that this inhibition was unrelated to relative root frequency. Experiment 2 replicated this result and showed that if the transposed letters of the root created a nonsense-root that had no lexical representation, then no inhibition and no facilitation were obtained. Finally, Experiment 3 demonstrated that in contrast to English, French, or Spanish, TL nonword primes did not facilitate recognition of targets, and when the root letters embedded in them consisted of a legal root morpheme, they produced inhibition. These results suggest that lexical space in alphabetic orthographies may be structured very differently in different languages if their morphological structure diverges qualitatively. In Hebrew, lexical space is organized according to root families rather than simple orthographic structure, so that all words derived from the same root are interconnected or clustered together, independent of overall orthographic similarity.

Keywords

Morphology; Letter Transposition; Hebrew; Masked-Priming

Lexical architecture is often described as a high-dimensional perceptual space that is defined in terms of orthographic, phonological, and semantic properties, where words are represented as points within this space. A typical example is attractor-based models where each word has a unique attractor, and the process of word recognition is then described in terms of a trajectory of the system through its state space (e.g., Rueckl, 2002; Harm, McCandliss & Seidenberg, 2003; Harm & Seidenberg, 2004; Elman, 2004). The initial point of this trajectory is some random position in the state space, and the final point is an attractor basin corresponding to the input word. In visual word recognition research, the relative position of word units is usually determined according to *orthographic* properties, so the distance between two words that are orthographically similar is necessarily shorter than the distance between words which are dissimilar. Also, since in most triangular models there are subspaces organized by different linguistic properties (orthographic, phonological, and semantic), with brief exposure durations,

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there is not enough time for the prime to cause the system to move very far in the phonological and semantic spaces, and hence the effects of the prime are primarily due to what happens in the front end of the system--the orthographic subspace, where orthographic similarity matters most (e.g., Rueckl, 2002; Elman 2004; and see Frost, Kugler, Deutsch, & Forster, 2005, for a discussion) Well-documented findings on form-orthographic priming (e.g., Ferrand & Grainger, 1994), the interaction of form-priming and neighborhood density (e.g., Forster & Taft, 1994), and the impact of letter transposition on reading (e.g., Perea & Lupker, 2003a) have provided empirical support for this type of lexical organization. Thus, following the prime GOWN, the recognition of the target TOWN will be facilitated because GOWN is adjacent to TOWN.

The distance metaphor of attractor-models is transformed into a set of excitatory and inhibitory connections between letter, letter-clusters and lexical units in parallel-activation models, where letter identity and letter position determine the extent of activation (e.g., IAM, McClelland & Rumelhart, 1981; the Dual-Route-Cascaded model, Coltheart, Rastle, Perry, & Ziegler, 2001, or the Multiple Read Out Model, Grainger & Jacobs, 1996). According to these models, DOWN would prime GOWN and TOWN not because they are located one next to the other in lexical space but because the activated letter units in DOWN activate GOWN and TOWN. Note, however, that the principle that orthographic similarity is the main constraint that governs lexical architecture and lexical access in alphabetic orthographies remains the same whether we describe it in terms of spatial locations or in terms of neural connections (see Grainger, 2008, for a recent review).

In this context, research in Hebrew, a Semitic language, provides a unique perspective. This is because, on the one hand, Hebrew has an alphabetic orthography where sequential and contiguous letter strings represent phonemes, and orthographic processing in that language should, therefore, be similar to that of Indo-European languages. However, on the other hand, Hebrew has a Semitic morphology, where all verbs and most nouns and adjectives are composed of two basic derivational morphemes: the *root* and the *word-pattern*. The *root* usually consists of three consonants, while the word-pattern consists of either vowels or a combination of vowels and consonants. Because roots and word-patterns are bound morphemes, and hence cannot function as independent words, only a combination of the two types of morphemes can form a grammatical word in Hebrew (Berman, 1978; Glinert, 1989). The most important aspect of Hebrew morphology which is relevant to the present study concerns the manner by which these two morphemes are combined. Unlike languages with concatenated morphology, the root and the word-pattern are not attached to each other linearly; rather, they are intertwined. The non-linear structure often obscures the phonological (and the orthographic) transparency of the two morphemes. For example, the Hebrew word /ti**lb**o**ʃ**et/ (written t**lb**w**s**t, “a costume”) is a derivation of the root **l.b.s**. This root is mounted on the phonological pattern /ti$\mathbf{C_1C_2}$o$\mathbf{C_3}$et/ (each C indicates the position of a root consonant). The root **l.b.s** alludes to the concept of wearing, whereas the phonological pattern /ti$\mathbf{C_1C_2}$o$\mathbf{C_3}$et/ is often (but not always) used to form feminine nouns. It is the merging of the root with the word pattern that forms the word meaning “costume”. Other phonological word-patterns may combine with the same root to form different words with different meanings that can be either closely or remotely related to the notion of wearing, and other roots may be combined with the word pattern /ti$\mathbf{C_1C_2}$o$\mathbf{C_3}$et/ to form feminine nouns.

In the last decade, the processing of morphological information in Hebrew has been extensively investigated in an array of experimental paradigms such as masked priming, cross-modal priming, and the monitoring of eye-movements (Feldman, Frost & Pnini, 1995; Frost, Forster & Deutsch, 1997; Deutsch, Frost, & Forster, 1998; Frost, Deutsch, & Forster, 2000; Frost, Deutsch, Gilboa, Tannenbaum, & Marslen-Wilson, 2000; Deutsch, Frost, Pollatsek, & Rayner 2000; Deutsch, Frost, Peleg, Pollatsek, & Rayner 2003; Velan, Frost, Deutsch & Plaut, 2005;

Deutsch, Frost, Pollatsek, & Rayner 2005; Frost, Kugler, Deutsch, & Forster, 2005). One consistent finding that emerged from all of the above studies is that root primes facilitate both lexical decision and naming of target words that are derived from these roots. Similarly, eye-movement studies demonstrated that a parafoveal preview of the root letters always resulted in shorter eye-fixations on targets that were root derivations. Taken together, these findings led us to suggest that the root morpheme serves as an organizing unit in the mental lexicon of Hebrew readers (e.g., Frost et al., 1997; Deutsch et al., 1998). More specifically, we suggest that words in Hebrew are clustered within a lexical space that is structured according to root families rather than simple orthographic structure, so that all words derived from the same root are interconnected or clustered together, independent of overall orthographic similarity. Note that the orthographic dissimilarity of two words sharing the same root may be significant (e.g., t**ks**w**r**t-**k**y**s**w**r** (/ti**k**ʃo**r**et/-/**k**iʃu**r**/) “communication”-“connection”, two derivations of the root **k.s.r**, which conveys the meaning of “tying”). According to this view, Hebrew lexical space is presumably organized very differently than that of English, French, or Italian. Instead of locating word units given their sequence of letters, root units would serve as the main attractors within the system, and all words derived from a given root would be located within the root neighborhood.

There are immediate empirical predictions emerging from this hypothesized organization of the mental lexicon. The first set concerns the effects of form-orthographic priming versus morphological priming. If lexical space in Hebrew is indeed defined by root families, one would predict that, in contrast to Indo-European languages, form-orthographic overlap between primes and targets will not result in priming for Hebrew words. In contrast, two words sharing a root will necessarily prime each other regardless of orthographic similarity, or semantic overlap. To examine this hypothesis, in a recent set of studies, we examined Hebrew-English bilinguals, contrasting form-orthographic and morphological priming effects in Hebrew and in English (Frost et al., 2005). We found that when tested in English, our bilingual speakers demonstrated robust form-priming. However, no such effect was obtained when these same subjects were tested with Hebrew material. By contrast, morphological priming effects were found to be stronger for Hebrew material than for English material (Frost, in press).

The second set of predictions is the focus of the present paper. It concerns the effects of letter transposition. In recent years, several studies have consistently reported robust form-orthographic priming effects when primes and targets shared all of the same letters but in a slightly different order (e.g., *gadren* priming *garden*,Perea & Lupker, 2003a; Perea & Lupker 2004; Schoonbaert & Grainger, 2004; and see Grainger & van Heuven, 2003 for a discussion). Moreover, transpositions of two adjacent letters in the prime led to significant semantic priming for related targets (JUGDE priming COURT; Perea & Lupker, 2003b). Masked priming with transposed-letters (TL) was reported in several languages including English (e.g., Perea & Lupker, 2003a), French (Schoonbaert & Grainger, 2004), Spanish and Basque (Duñabeitia, Perea & Carreiras, 2007), and even Japanese Katakana (Perea & Perez, 2009). Several studies conducted by Perea and his colleagues, examined the locus of the effect, demonstrating that it is orthographic rather than phonological (Perea & Carreiras, 2006a; Perea & Carreiras, 2006b; Perea & Carreiras, 2008; Lupker, Perea, & Davis, 2008; Perea & Perez, 2009).

The finding that robust form-orthographic priming can be obtained even with changes in letter order has revolutionized the modeling of visual word recognition. It suggested a substantial flexibility in the coding of letter position, and hence presented immense difficulties for slot-based coding computational models, which encode letter position in absolute terms (e.g., the interactive activation (IA) model by McClelland and Rumelhart, 1981, or the dual-route cascaded (DRC) model by Coltheart, Rastle, Perry, Ziegler, and Langdon, 2001). Consequently, a new generation of computational models that focus on context-sensitive coding of relative letter position has emerged (e.g., the SOLAR model, Davis, 1999; the

SERIOL model, Whitney, 2001, Grainger & Whitney, 2004; the Bayesian Reader Model, Norris, 2006; the Overlap model, Gomez, Ratcliff & Perea, 2008; and see Grainger, 2008 for a review). For example, Davis (1999) suggested that letter position is encoded by the relative pattern of activities across letters in a word; hence, the initial letter attains the highest activation and activation levels decrease along the letter-string. Similarly, Whitney and her colleagues have suggested that letter position coding is based on "open bigram" units (Whitney, 2001; Grainger & Whitney, 2004; Whitney, 2008). Open bigrams do not contain precise information about which letter is adjacent to which (i.e., contiguity), aside from the initial and final letters, which do have position marking. For example, the word *FORM,* would be represented by activation of the bigram units #F, *FO, OR, RM, FR, OM,* and *M#,* where # represents a word boundary. A transposition prime, such as FROM, would then share all but one of these units, namely *#F, FR, FO, RM, OM* and *M#.* Another alternative to account for the letter transposition effect is provided by the Overlap model (Gomez et al., 2008) and the later versions of the Bayesian Reader model (Norris & Kinoshita, 2008). These models interpret effects of transposition in terms of a noisy position scheme in which letter-position information becomes available more slowly than letter identity information. All of these models, however, naturally assume that the processing system treats two printed stimuli with letter transpositions (e.g., judge-jugde) as similar because they share the same set of letters.

What about Hebrew then? How would letter transpositions affect reading in Hebrew? If lexical access in Hebrew is indeed based on a preliminary search of a tri-consonantal root entry, then the sensitivity of Hebrew readers to letter transposition may be significantly increased relative to readers of Indo-European languages. The a-priori support for such a hypothesis is based on simple combinatorial arguments. The Hebrew language has a listing of about 3000 tri-consonantal roots (Ornan, 2003), which are represented by the 22 letters of the alphabet. The immediate combinatorial implication is that many roots have to share the same set of three consonants (or letters) but in a different order. For example, the letter order of the root **s.l.x** ("to send") can be altered to produce the root **x.l.s** ("to dominate"), **x.s.l** ("to toughen"), and **l.x.s** ("to whisper"). In fact, tri-consonantal roots that do not share their set of three letters with other roots are scarce. If lexical access in Hebrew requires the identification of a specific root, then root-letter order is critical, and the processing system should not be able to tolerate transpositions involving root letters. This is because all derivations of **x.l.s**, for example, need to be differentiated from those of **s.l.x, l.x.s,** and **x.s.l**. Borrowing the terms of the Overlap model (Gomez et al., 2008), the processing system of Hebrew readers would not allow any noisy position schemes for root letters. If this hypothesis is correct, then priming of targets by transposed-letter primes will not work in a Semitic language such as Hebrew. The letter-transposition effect could then be taken to reflect the specific characteristics of Indo-European languages, rather than a general property of the visual processing of words in alphabetic orthographies.

Velan & Frost (2007) investigated this possibility by examining the reading performance of Hebrew-English bilinguals, using Rapid Serial Visual Presentation (RSVP), (see Potter, 1984). In this study, Hebrew-English balanced bilinguals were presented with sentences in English and in Hebrew, half of which had transposed-letter words, and half of which were intact. The sentences were presented on the screen word-by-word. Velan and Frost found a marked difference in the effect of letter-transposition in the two languages. For English materials, the report of words was virtually unaltered when sentences included words with transposed letters. Moreover, most subjects were unaware of the transposition manipulation. This finding seems to converge with recent results which report strong masked-priming effects for transposed letters in English. Very different results, however, were found for the Hebrew material. The correct report of Hebrew words dropped dramatically in sentences containing transpositions, and detection of transposition was immediate. Since the participants in the Velan and Frost (2007) study were bilingual subjects in a within-subject design, the difference between the Hebrew and the English blocks can only be attributed to a linguistic factor and not to experimental procedures or to individual differences between subjects.

We now come to the aim of the present investigation. In the following experiments, we examined the architectural properties of lexical space in Hebrew by investigating how different sequences of root letters affect word recognition. More specifically, we employed the masked priming paradigm (Forster & Davis, 1984) to examine the impact of letter-transpositions when the transposed letters of primes and targets were letters belonging to the root. If words in Hebrew are organized in the mental lexicon according to root families and the lexical search is initially concerned with locating a root-morpheme entry, then the order of root letters is crucial. Thus, in contrast to English, while extracting the root information from the printed word, readers must register not only the identity of the root letters but also their position relative to one another. The first implication to consider is that transpositions of letters of the prime that disrupt the sequence of consonants of the root morpheme should not produce any priming. Moreover, if the transposition of letters results in another root, then instead of prime-target facilitation we should expect prime-target inhibition. This is because words containing similar roots may not necessarily be located near each other. That is, the roots **s.l.x** (meaning to send) and **l.x.s** (meaning to whisper) are no more similar than **s.l.x** and **d.b.r** (meaning to speak), and, therefore, they might be located far apart from each other in lexical space. To cast it in interactive activation terms, since the major aim of the Hebrew lexical-processing system is to differentiate between **s.l.x and l.x.s**, as well as between their respective derivations, the set of excitatory and inhibitory connections between letter units and root-morpheme units should ensure that the correct root is unequivocally activated by a given sequence of root-letters. The most probable architecture would require then, that activation of root morpheme units by letter units would be strictly constrained by relative letter-position. More importantly, strong inhibitory connections are expected between two roots sharing the same letters in a different order, even stronger than for two roots that do not share letters.

To further examine the structure of lexical space in Hebrew, we conducted three experiments. Experiment 1 examined the impact of root-letter transpositions that resulted in another legal root. Experiment 2 extended this investigation to examine the impact of root-letter transpositions that resulted in a nonsense root. Finally, in Experiment 3, our aim was to more closely mirror the traditional priming procedure employed in Indo-European languages, given the inherent differences between the languages' morphology. Therefore, rather than using three letter root primes, the primes were nominal forms derived from a transposition of the three root letters of the target.

Experiment 1

Previous studies in Hebrew using masked priming showed that primes consisting of root letters facilitate lexical decisions for targets which are root derivations (Frost et al., 1997). The aim of Experiment 1 was to examine whether a transposition of the root letters which results in another legal root facilitates or inhibits lexical decisions for targets derived from the original root. In this respect, the present experiment diverges from most masked priming experiments in Indo-European languages that employed transpositions which were nonword primes (e.g., *caniso* priming *casino* (Perea & Lupker, 2004)). In Experiment 1, transpositions created an existing root.

Since the transposed root letters in Experiment 1 formed another legal root and could be read as a word, and since masked form-priming in Indo-European languages has been shown to be sensitive to the frequency of the prime (e.g., Grainger, Colé & Segui, 1991), we set our experimental design to also examine whether the potential impact of letter transposition is modulated by the relative frequencies of the roots. Subjects were thus presented with target words, all regular root derivations, which were either derived from low- or from high-frequency roots relatively to the TL primes roots (for example, **s.l.x** (to send), is very frequent, whereas **x.s.l** (to strengthen or toughen) is not). Target words were paired with three different primes: in the related condition, the primes were the three letters of the root (e.g. **x.s.b** meaning "to think" priming the root derivation m**xsb**h, pronounced as /ma**x**ʃa**v**a/ meaning "a thought"). The purpose of the related condition was to obtain a baseline for the maximal morphological priming effect when the targets are indeed primed by their roots. Indeed, Frost et al. (1997) have shown that root priming creates a robust effect in Hebrew. In the TL condition, primes involved transposing two of the root letters, and the transpositions formed another root (e.g. **x.b.s** meaning "to bandage" priming m**xsb**h). Finally, in the orthographic control condition, primes for the same targets were three letters contained in the target, but not exclusively the letters of the root (e.g., **x.s.h** priming m**xsb**h). Half of these three-letter combinations could be read as words and half could not. Previous studies in Hebrew revealed that prime lexicality does not affect priming (Frost et al., 1997); however, this design allowed us to ensure that our priming effects are indeed not confounded with prime lexicality. For half of the stimuli, the roots of the TL condition were more frequent than the targets' roots, and for half they were less frequent. This design allowed us to investigate whether transposed-letter roots produce facilitation or inhibition for the target derivations, and whether the potential facilitation or inhibition of the transposed roots is modulated by the relative frequencies of the possible root alternatives.

Method

Participants—Fifty-one students from the Hebrew University participated in the experiment for course credit or for payment. The participants in this and the following experiments had either normal or corrected to normal vision and were native speakers of Hebrew.

Stimuli and Design—The stimuli consisted of 36 target words. All targets were nouns which were derived from tri-consonantal roots. Targets were four to six letters long and contained two to four syllables, with five to eight phonemes. Their mean number of letters was 5.11 and their mean number of phonemes was 5.89. The mean word frequency per one million words was 14.6, range: 1-113. The words were root derivations that were derived via a variety of common word patterns in Hebrew. The target words were paired with 3×36=108 primes to create three experimental conditions: (a) the root condition - primes were the roots from which the targets were derived, (b) the TL-root condition - primes consisted of the transposed letters of the root which formed an existing root, (c) the control condition - primes consisted of a sequence of three letters contained in the target, which were not exclusively the three letters of the root (meaning two root letters could be present, at most). About half of these three-letter combinations could be read as words and the rest could not. Previous research has shown that prime lexicality does not effect lexical decisions in Hebrew (Frost et al., 2005), however, we wanted to confirm this hypothesis. To examine whether the difference in priming between the root and the TL-root condition is determined by the relative frequency of the root and the transposed root, half of the target words were derived from roots whose frequency was lower than that of the TL-roots (mean root frequency 356.11 and 1674 respectively) and half were derived from roots whose frequency was higher than that of the TL-roots frequency (mean root frequency 1466.11 and 374.72 respectively)[1]. An example of the stimuli used in the experiment is presented in Table 1, the stimuli are presented in Appendix B. The nonwords consisted of 36 pseudo-nouns which were derived from existing word-patterns and tri-consonantal non-existing roots. Nonword targets were four to six letters long and contained two to three syllables with five to eight phonemes. Their mean number of letters was 5.08 and their mean number of

[1]Root frequency is the total sum of the root's derivations frequency. All frequency assessments were based on the word-frequency database for printed Hebrew by R. Frost, R. & D. Plaut. http://word-freq.mscc.huji.ac.il/index.html

phonemes was 5.94. Similar to the word targets, the nonwords were also divided into three experimental conditions: “related,” “TL-related,” and control, although relatedness was determined simply by repeating the pseudo-root letters.

The stimuli were divided into three lists. Each list contained 6 words and 6 nonwords in each of the six experimental conditions. We were concerned with the very small number of items per experimental condition. However, we were restricted to a relatively small number of target roots because only 36 roots could produce TL-root transpositions with discrepant frequency ratios. The stimuli were rotated within the six conditions in each list in a Latin square design. Seventeen different participants were tested in each list. This procedure allowed each participant to provide data points in each condition while avoiding stimulus repetition effects.

Procedure and Apparatus—The software used for presentation of stimuli and for measuring the reaction times was the DMDX display system (Forster & Forster, 2003). Each trial consisted of three visual events. The first was a forward mask consisting of a row of seven hash marks, which appeared for 500 ms. The mask was immediately followed by the prime, with an exposure duration of 40 ms. The prime was immediately followed by the target word, which remained on the screen for an additional 1000 ms. The time lag between the subject's response and the next stimuli was 1000 ms. All visual stimuli were centered in the viewing screen and were superimposed on the preceding stimuli.

Methodological considerations

All of the experiments in the present study were conducted using the masked priming paradigm. The application of this procedure to Hebrew requires the elucidation of several important methodological issues, which are relevant to the interpretation of the data.

Print—In Hebr*ew,* letters mostly represent consonants while most of the vowels can optionally be superimposed on the consonants as diacritical marks (“points”). The diacritical marks are, however, omitted from most reading material, and are usually used only in poetry, children's literature, and religious scriptures. The stimuli in our study were presented in unpointed Hebrew characters. This is because adult readers read unpointed print almost exclusively. However, the target words were phonologically unambiguous.

Prime-target separation—In English the separation of primes and targets is often achieved by using upper-case and lower-case scripts. Although Hebrew has two forms of scripts (square and cursive), the cursive script is rarely used in printed material, and we therefore adopted the manipulation of size rather than form. Thus, two versions of the same square font, which differed in their relative size, were used. Targets were always presented in the larger font (25% larger than the primes, David 16 and 20 for primes and targets, respectively). This guaranteed complete visual masking of the primes by the targets, and also made the primes and the targets physically distinct stimuli (see Frost, Ahissar, Gotesman, & Tayeb, 2003, for a detailed description).

Choice of control primes—There is always a question regarding the “right” control condition relative to which facilitation or inhibition is calculated, and one can find pros and cons for any rationale chosen. Our choice of an orthographic control was to keep the same letter overlap as the related conditions and not to use all-letter-different controls. This has been a longstanding choice (Frost et al., 1997, 2005; Deutsch et al., 1998, 2000), since it has been shown that some letter overlap in Hebrew produces small facilitation due to prelexical-peripheral factors (see Frost et al., 2005, for a detailed discussion), and our aim in the present study was to assess the effects of letter transposition relative to this baseline.

Choice of nonwords—In all three experiments, nonwords were formed by combining non-existing roots with existing word-patterns. We used non-existing roots, to avoid a possible conflict between the negative response to the nonwords, and a positive response that could be elicited following the recognition of an existing root morpheme. We used existing word-patterns to maintain the Semitic structure of our stimuli, so that word-nonword decisions would not be based upon a fast and superficial analysis.

Results and Discussion

The reaction times (RTs) were averaged for correct responses in the three experimental conditions across participants and across items. For each participant, RTs that were outside a range of 2 SD from the participant's mean were curtailed. Establishing cutoffs of 2 SDs above and below the mean for each participant minimized the effect of outliers. Any RT exceeding these cutoffs was replaced by the appropriate cutoff value. Trials on which an error occurred were discarded. This procedure was repeated in all of the following experiments.

The effects of the root and TL-root primes were assessed relative to the control baseline. The results are presented in Table 2. Lexical decisions for targets were facilitated in the root condition where the primes and the targets shared the same root (+21 and +18 msec, for high- and for low-frequency roots, respectively). This finding replicates the root priming effect reported by Frost et al. (1997). The more interesting result, however, concerns the TL-root condition. When primes consisted of a different root comprised of the same letters as the target's root, inhibition rather than facilitation was observed for both high- and low-frequency root primes (-14 and -10 msec, respectively).

The results were subjected to a three-way ANOVA in which the type of prime was one factor (root, TL-root, control) and the root frequency (root frequency higher than TL-root, root frequency lower than TL-root), was another. The third factor, word list, was introduced throughout the study merely to extract any variance due to list counterbalancing. We will therefore not report on it.

The overall ANOVA revealed a main effect of type of prime that was significant across subjects (F_1) and items (F_2), for response latencies, $F_1(2,96) = 19.7$, $MSE = 1337$, $p < 0.001$; $F_2(2,20) = 31.4$, $MSE = 333$, $p < 0.001$; min$F'(2,88) = 12.1$, as well as for errors, $F_1(2,96) = 4.0$, $MSE = 133$, $p < 0.022$; $F_2(2,20) = 4.1$, $MSE = 45$, $p < 0.03$; min$F'(2,67) = 2.0$) This main effect was created by both the facilitation in the root condition and the apparent inhibition of the TL-root condition. The main effect of root-frequency was significant in the subject analysis, as targets derived from high-frequency roots were responded to faster than targets derived from low-frequency roots, but not in the item analysis, $F_1(1,48) = 25.0$, $MSE = 747$, $p < 0.001$; $F_2 < 1.0$; min$F'(1,11) = 0.9$. More importantly, however, the interaction of type of prime and root frequency was not significant, F_1, $F_2 < 1.0$; min$F'(2,38) = 0.06$. Thus, neither the facilitation nor the inhibition was modulated by frequency.

We now turn to a series of planned comparisons which are the focus of the experiment. The facilitation in the root-prime condition was significant for both participants and item analyses, $F_1(1,48) = 13.7$, $MSE = 1428$, $p < 0.001$, 95% CI = 19.6 ± 10.6; $F_2(1,10) = 24.4$, $MSE = 395$, $p < 0.001$, 95% CI = 23.11 ± 6.7; min$F'(1,46) = 8.8$. This finding replicates the root-priming effect reported by Frost et al. (1997), in their seminal study on Hebrew morphology. However, the most interesting results concern the TL-root priming condition. A planned comparison revealed that the inhibitory effect caused by the TL-root primes (-12 msecs) was significant for participants, $F_1(1,48) = 5.9$, $MSE = 1298$, $p < 0.02$, 95% CI = (-12.3) ± 10.1, as well as for items, F_2 (1,10) =6.4 MSE = 290, p < 0.03, 95% CI=(-10.2) ± 5.8; min$F'(1,35) = 3.1$. No significant effects were found for errors, F_1, $F_2 < 1.0$; min$F'(1,40) = 0.0$). No effects were found for nonwords. This is not surprising since facilitation or inhibition in the masked priming paradigm is considered to reflect lexical processes and, therefore, depends on the existence of a lexical representation (Forster & Davis, 1984; Forster, 1987; Forster, Davis, Schocknecht & Carter, 1987). Finally, no differences were found between the control primes that could be read as words and those which could not (M = 563 and M = 589 respectively; $F(1,34)=2.342$, MSE = 2573, $P < 0.15$), suggesting that prime lexicality did not affect our findings.

The striking result of Experiment 1 is that TL-primes, which consist of an existing root, inhibited lexical decisions for targets that were derived from roots sharing the same letters but in a different order. Thus, whereas the root **x.s.b** facilitated lexical decision for targets derived from it (m**xsb**h), **x.b.s** produced inhibition relative to a control of three letters of the target that was not the root morpheme. Moreover, this inhibition does not seem to be dependent on the relative frequency of transposed and non-transposed root letters. Note that previous studies which investigated how frequency modulates inhibitory or facilitatory masked priming effects in Indo-European languages examined the relative frequency of *words* that served as either primes or targets (e.g., Segui & Grainger, 1990; Davis & Lupker, 2006; Nakayama, Sears & Lupker, 2008; Acha & Perea, 2008). In contrast, in Experiment 1 we were concerned with the frequency of the *root morpheme* from which the targets were derived.

Interestingly, our priming manipulation was akin to several studies in Indo-European languages that examined priming of targets by a subset of their letters. Although two studies in Dutch demonstrated that primes that were either orthographic subsets or supersets of the targets produced inhibition in masked priming (Drews & Zwitserlood, 1995; De Moor & Brysbaert 2000), several studies by Grainger and his colleagues (e.g., Peressotti & Grainger, 1999; Grainger, Granier, Farioli, Van Assche & van Heuven, 2006), which have systematically examined the priming effect of subsets of letters contained in the target, have shown otherwise. These studies, conducted in French, repeatedly found facilitation when letters remained in the same order as in the target, even with relatively minor orthographic overlap (4-letter primes with 9-letter targets). Thus, similar to our manipulation, subsets of letters in French (such as BLCN) produce faster RTs to word targets (such as BALCON) relative to subsets of different letters (such as TPVF). These findings suggest that, in general, in French, like in Hebrew, subset primes facilitate, not inhibit recognition of targets. However, the results of Experiment 1 provide an interesting contrast to the studies in French. First, in Hebrew, subsets comprised of the root letters always produced facilitation relative to control subsets that are not root letters. Second, in Hebrew, the TL condition produced active inhibition. The main difference is that in Hebrew, in contrast to English or French, the specific subset of consonant letters was a morpheme.

Our results suggest that the extraction of the root morpheme is an early component of visual word recognition in Hebrew (Frost et al., 2005; Velan & Frost, 2007), and that the location of any root derivation in lexical space requires an accurate registry of the exact order of root letters. Errors concerning this order seem to hinder lexical access because the root and the TL-root primes are not necessarily located in adjacent areas in lexical space. The lexical distance between the root and the TL-root also appears to be independent of their relative frequency.

Experiment 2

In Experiment 1 all TL-primes consisted of another existing root. The aim of Experiment 2 was to examine whether the inhibition produced from the TL-primes is due to some lexical competition between the target root and the TL-root primes, or whether any transposition that disrupts the order of the root letters simply requires additional time for lexical search. We addressed this question by contrasting two types of TL primes: transpositions that consisted of existing roots and transpositions that consisted of nonsense roots. As we noted in the description of Hebrew morphology, not all letter transpositions of a given root create a meaningful root. Thus, we were able to compare the impact of transpositions that resulted in a root morpheme to those that resulted in a sequence of three letters that had no meaning and, therefore, no lexical representation.

Method

Participants—Eighty students from the Hebrew University received course credit or payment for participating in the experiment.

Stimuli and Design—The stimuli consisted of 48 target words. All targets were nouns which were derived from regular tri-consonantal roots. Targets were four to seven letters long and contained two to four syllables with five to nine phonemes. Their mean number of letters was 5.35 and their mean number of phonemes was 6.44 (mean word frequency per one million words: 20.23, range: 1-246). The words were root derivations that were derived in a variety of common word patterns in Hebrew. The target words were paired with 48 primes to create four experimental conditions: (a) the root condition - primes were the roots from which the targets were derived, (b) the TL-existing-root condition - the primes consisted of the transposed letters of the root which formed an existing root, (c) the TL-nonsense-root condition - the primes consisted of the transposed letters of the root which formed a non-existing root and (d) the control condition - the primes consisted of a sequence of three letters contained in the target, which were not the three letters of the root, (although two root letters could be present). Half of these three-letter combinations could be read as words and half could not. An example of the stimuli used in the experiment is presented in Table 3, the stimuli are presented in Appendix C. The nonwords consisted of 48 pseudo-nouns which were derived from existing word-patterns and non-existing tri-consonantal roots. Nonword targets were four to seven letters long, and contained two to four syllables with five to nine phonemes. Their mean number of letters was 5.23 and their mean number of phonemes was 6.17. Similar to the word targets, the nonwords were also divided into four experimental conditions to mimic the word stimuli.

The stimuli were divided into four lists. Each list contained 12 words and 12 nonwords in each of the four experimental conditions. The stimuli were rotated within the four conditions in each list in a Latin square design. Twenty different participants were tested in each list, performing a lexical decision task. This procedure allowed each participant to provide data points in each condition while avoiding stimulus repetition effects.

Procedure and Apparatus—The procedure and apparatus were identical to those in Experiment 1.

Results and Discussion

The reaction times (RTs) were averaged for correct responses in the four experimental conditions across participants and across items. Within each participant, RTs that were outside a range of 2 SDs from the participant's mean were curtailed. The priming effects of the root, the TL-existing-root, and the TL-nonsense-root conditions were assessed relative to the control baseline. The results are presented in Table 4. Lexical decisions for targets were facilitated in the root condition (+19 ms) where the primes and the targets shared the same root. The more interesting results, however, concern lexical decisions in the TL conditions. When TL-primes consisted of an existing root an inhibition of -9 ms was obtained. This result provides a replication of the findings of Experiment 1. In contrast, when TL-primes consisted of a nonsense root, response latencies were virtually identical to those in the control condition.

The results were subjected to a two-way ANOVA in which the type of prime was one factor (root, TL-existing-root, TL-nonsense-root, control), and word list was the other. The ANOVA revealed a main effect of type of prime that was significant across subjects and items, for response latencies, $F_1(3,228) = 27.6$, $MSE = 422$, $p < 0.001$; $F_2(3,33) = 27.3$, $MSE = 288$, $p < 0.001$; $\min F'(3,114) = 13.7$, as well as for errors, $F_1(3,228) = 9.9$, $MSE = 44$, $p < 0.000$; $F_2(3,33) = 6.9$, $MSE = 38$, $p < 0.001$; $\min F'(3,89 = 4.1$. This main effect was created by both the facilitation in the root condition and the apparent inhibition of the TL-existing-root condition. Planned comparisons revealed that the facilitation due to root primes was significant for RTs, $F_1(1,76) = 34.8$, $MSE = 416$, $p < 0.001$, 95% CI = 19.0 $\pm$ 4.5; $F_2(1,11) = 49.2$, $MSE = 184$, $p<0.001$, 95% CI = 19.4 $\pm$ 3.9; $\min F'(1,50) = 20.4$, and marginal for errors, $F_1(1,76) = 3.2$, $MSE = 39$, $p < 0.08$, 95% CI = 1.8 ± 1.4; $F_2(1,11) = 4.5$, $MSE = 17$, $p < 0.06$, 95% CI = 1.8 ± 1.2; $\min F'(1,49)=1.9$. Similar to Experiment 1, this finding again conforms to the well-documented root priming effect in Hebrew (Frost et al., 1997; Deutsch et al., 1998). The inhibition caused by existing root primes was significant for RTs, $F_1(1,76) = 8.8$, $MSE = 388$, $p < 0.004$, 95% CI = (-9.3) ± 4.4; $F_2(1,11) = 6.15$, $MSE = 417$, $p < 0.03$, 95% CI = (-10.3) ± 5.9; $\min F'(1,30)=3.6$, as well as for errors, $F_1(1,76) = 6.7$, $MSE = 43$, $p < 0.01$, 95% CI = (-2.7) ± 1.5; $F_2(1,11) = 6.8$, $MSE = 26$, $p < 0.02$, 95% CI = (-2.7) ± 1.5; $\min F'(1,39) = 3.4$, as more errors were found in the transposed-letter conditions. The TL-nonsense-root condition did not produce any effect for RTs, $F_1 < 1.0$; $F_2(1,11) = 1.62$, $MSE = 222$, $p < 0.2$, 95% CI = (-3.9) ± 4.3; $\min F'(1,84) = 0.3$, as response latencies in this condition were almost identical to those in the control condition. However, errors in this condition were higher than in the control condition, $F_1(1,76) = 9.0$, $MSE = 43$, $p < 0.004$, 95% CI = (-3.1) $\pm$ 1.5; $F_2(1,11) = 4.8$, $MSE = 49$, $p < 0.05$, 95% CI = (-3.1) ± 2.0; $\min F'(1,25) = 3.1$. Finally, the difference between the TL-existing-root condition and the TL-nonsense condition (7 ms) was significant for participants but not for items $F_1(1,76) = 4.81$, $MSE = 446$, $p < 0.03$, 95% CI = 7.3 ± 4.7; $F_2(1,11) = 2.4$, $MSE = 417$, $p < 0.15$, 95% CI = 6.46 ± 5.9; $\min F'(1,24) = 1.6$. No significant effects were found for errors, F_1, $F_2 < 1.0$; $\min F'(1,44)=0.09$).

As in Experiment 1, the nonwords did not produce any significant effect. Again, no differences were found between the control primes that could be read as words and those that could not ($M = 544$ and $M = 532$ respectively; $F(1,46)=1.89$, $MSE = 935$, $P < 0.12$), suggesting that prime lexicality did not affect our findings.

The results of Experiment 2 replicate the findings of Experiment 1. Again, a transposition of root letters that comprised another meaningful root slowed the recognition of targets derived from the original non-transposed root morpheme. However, interestingly, when transposition of the root letters did not create a meaningful root but rather represented a nonsense sequence of three letters, responses to targets were not slowed nor speeded relative to the control condition. Hence, it seems as if the processing system considers the TL-nonsense roots irrelevant to lexical search of the targets. Our findings lead us to suggest that the inhibition caused by transposing root letters does not stem from the simple disruption of letter-order but rather from the competition of another lexical root unit. Note, however, that we did find a higher error rate in the TL-nonsense root condition than in the control condition. We will further address this discrepancy when discussing the findings of Experiment 3.

Experiment 3

Experiments 1 and 2 demonstrated the potential inhibition caused by transposition of root letters as priming stimuli, when targets were root derivations. However, the stimuli in these experiments did not resemble those employed in Indo-European languages. The facilitation caused by TL-primes in English, French, or Spanish was demonstrated when primes and targets contained the same number of letters as well as an identical letter sequence, aside from the transposed letters. What remains to be investigated is whether facilitation or inhibition is obtained when such stimuli are used in Hebrew. In Experiment 3 we mimicked the procedure employed in Indo-European languages (e.g., Perea & Lupker, 2003a; Schoonbaert & Grainger, 2004; Perea & Lupker, 2004) though without disregarding the status of the root letters in

Hebrew. Subjects were presented with root derivations as targets, whereas the primes were nonwords that had the same number of letters but included a transposition of the target's root letters. There were two TL conditions. In the TL-existing-root condition the primes were constructed by transposing the root letters of the derived targets, creating another meaningful root, and then combining it with the same word-pattern, only that the final product of the TL-root and word-pattern did not produce an existing word (not all meaningful roots in Hebrew can be combined with all word-patterns). For example, the target word m**drg**h /ma**dr**e**g**a/, meaning "a stair," is derived from the root **d.r.g.**, meaning "to grade," and the word-pattern /ma$\mathbf{C_1C_2}$e$\mathbf{C_3}$a/ (written m$\mathbf{C_1C_2C_3}$h). The prime for m**drg**h in the TL-existing-root condition was m**grd**h (/ma**gr**e**d**a/), which is derived from the root **g.r.d**, an existing root having the meaning of "scratching," a transposition of **d.r.g.** But note that when the meaningful TL-root **g.r.d** is combined with the word pattern /ma$\mathbf{C_1C_2}$e$\mathbf{C_3}$a/, it creates a pseudoword, which bears no meaning. In the other TL condition, the TL-nonsense root condition, m**drg**h was primed by m**rdg**h (/ma**rd**e**g**a/). m**rdg**h has the same word-pattern /ma$\mathbf{C_1C_2}$e$\mathbf{C_3}$a/, however, it is created by combining it with the nonsense-root **r.d.g.**, also a transposition of **d.r.g**. In other words, the target m**drg**h could be primed by m**grd**h, a pseudo-word that contains a meaningful TL-root, or by m**rdg**h, a pseudo-word that contains a nonsense TL-root. The aim of the experiment was to examine whether a pattern of inhibition or facilitation emerges when we employ TL nonwords as primes, similar to the parallel studies in English, French, or Spanish.

Method

Participants—Eighty four students from the Hebrew University received course credit or payment for participating in the experiment.

Stimuli and Design—The stimuli consisted of 40 target words. All targets were nouns which were derived from regular tri-consonantal roots. Targets were five to seven letters long and contained three syllables with seven to nine phonemes. Their mean number of letters was 5.45 and their mean number of phonemes was 7.36 (mean word frequency per one million words: 8.68, range: 1-124). The words were root derivations that were derived in a variety of common word patterns in Hebrew. The target words were paired with 40 primes to create four experimental conditions: (a) Identity - primes were identical to the target word, (b) the TL-existing root condition - primes were a derivation of the transposed letters of the target root which form an existing root but a non-existing derivation, (c) the TL-nonsense root condition - primes were a derivation of the transposed letters of the target root which form a non-existing root, and of course a non-existing derivation, (d) the control condition - primes were a derivation of a pseudo-root which differed from the target's root by two letters. Note that all prime derivations were derived from the same word-pattern as the target. An example of the stimuli used in the experiment is presented in Table 5, the stimuli are presented in Appendix D.

When selecting the stimuli, we had significant constraints. First, given the well-documented impact of transposing the initial word-letter (e.g. Guerrera & Forster, 2008), the first letter of all of our target words could not be a root letter but rather a word-pattern letter. However, as most word-patterns begin with the consonants h,m,t,l, we inserted 40 word and nonword fillers to obtain a variable list of Hebrew words, in order to prevent the subjects' developing any strategies of root extraction. Second, we were constrained to root derivations in which the root letters are orthographically contiguous, so that we could transpose two adjacent root letters to create the existing-root and nonsense-root conditions. Obviously, we were constrained to a limited set of roots for which one transposition resulted in an existing root and the other in a non-existing root. Finally, given the demonstration in English, Spanish and Basque that TL effects are significantly reduced if morphemic boundaries are crossed (Christianson, Johnson, & Rayner, 2005; Duñabbeitia, Perea & Carreiras, 2007), we ensured that only two adjacent root-letters were transposed so that the continuity of the letters of the root was not orthographically compromised by letters belonging to the word-pattern[2].

The nonwords were pseudo-nouns which were derived from existing word-patterns but non-existing tri-consonantal roots. Nonword targets were five to seven letters long, and contained three syllables with seven to nine phonemes. Their mean number of letters was 5.3 and their mean number of phonemes was 7.35. Similar to the word targets, the nonwords were also divided into four experimental conditions, to mimic the words.

Procedure and Apparatus—The procedure and apparatus were identical to those employed in the previous experiments.

Results and Discussion

The reaction times (RTs) were averaged for correct responses in the four experimental conditions across participants and across items. Within each participant, RTs that were outside a range of 2 SDs from the participant's mean were curtailed. Trials on which an error occurred were discarded. For unknown reasons, eight stimuli resulted in an exceeding number of errors (25%-35% across all subjects). We thus removed these stimuli from the analysis.

The effect of the Identity, TL-existing-root, and TL-nonsense-root primes were assessed relative to the control baseline. The results are presented in Table 6. Lexical decisions for targets were facilitated in the Identity condition (+29 ms), where the prime and the target were identical. When primes were derived from a different root with the same letters as the target's root (TL-existing-root condition), an inhibition of -11 msecs was obtained. Yet when primes consisted of a derivation of a non-exiting root with the same letters as the target's root (TL-nonsense-root condition), a non-significant small facilitation of +3 msecs was obtained.

ANOVAs based on the participant and item response latencies and percentage of errors were conducted with type of prime as the main factor (Identity, TL-existing-root, TL-nonsense-root, 2 letters different control), and list as another factor.

The main effect of type of prime revealed a significant effect in the RT analysis for both participants and items, $F_1(3,240) = 46.6$, $MSE = 808$, $p < 0.001$; $F_2(3,21) = 35.7$, $MSE = 428$, $p < 0.001$; minF' $(3,62) = 20.2$. The error analysis also revealed a significant prime condition for both participants and items, but this was mainly due to the smaller error rate in the identity condition, $F_1(3,240) = 4.86$, $MSE = 77$, $p < 0.002$; $F_2(3,21) = 5.0$, $MSE = 28$, $p < 0.008$; min$F'(3,79) = 2.5$. Planned comparisons revealed an Identity priming effect significant for both participants and items, $F_1(1,80) = 73$, $MSE = 826$, $p < 0.000$, 95% CI = 29 ± 6.2; $F_2(1,7) = 121$, $MSE = 217$, $p < 0.001$, 95% CI = 40.5 ± 5.3; min$F'(1,40) = 45.5$.

The most interesting result, however, is the different effects found for the TL-existing-root condition and the TL-nonsense-root condition. For the TL-existing-root condition, a planned comparison revealed a highly significant inhibitory priming effect for participants, $F_1(1,80) = 7.6$, $MSE = 687$, $p < 0.007$, 95% CI = (-11.1) ± 5.7, but marginal in the item analysis $F_2(1,7) = 3.12$, $MSE = 469$, $p < 0.1$, 95% CI = (-9.6) ± 7.8; min$F'(1,14) = 2.2$. This was due mainly to the small number of items in the analysis: 8 items per subject per condition. The small number of items is due to the difficulty in finding roots whose transposition results in another existing root on the one hand, and in a pseudo-root on the other, as discussed above. The TL-nonsense-root condition did not produce any effect for RTs, as response latencies in this condition were almost identical to those in the control condition, F_1, $F_2 < 1.0$; min$F'(1,28) = 0.3$. Finally, planned comparisons between the TL-existing-root, and the TL-nonsense-root conditions

[2]In unpointed printed Hebrew some of the vowels of word-patterns do not appear as letters in print.

revealed a significant difference for both participants and items $F_1(1,80) = 11.1$, $MSE = 770$, $p < 0.001$, 95% CI = 3.1 ± 5.4; $F_2(1,7) = 6.7$, $MSE = 493$, $p < 0.04$, 95% CI = 0.0 ± 8.1; min$F'(1,17) = 4.2$. No effect was found for errors or for nonwords, F_1, $F_2 < 1.0$.

Experiment 3 thus demonstrates that in Hebrew, when the root letters are transposed, the TL priming effect found in Indo-European languages is absent: TL nonword primes do not facilitate lexical decisions for targets. Moreover, if the root letter transpositions result in an existing root, the TL-primes seem to hinder recognition of the targets. It is important to note that inhibition in Experiment 3 was obtained when the root letters embedded in the prime corresponded to an existing root, yet the primes were nonwords. In Indo-European languages, inhibition effects were reported only when TL primes were target neighbors (e.g., clam-calm, Acha & Perea, 2008). This reinforces the centrality of the root in Hebrew lexical access.

General Discussion

We conducted three experiments to examine the impact of letter transpositions on word recognition in Hebrew. In Experiment 1, we found that TL root primes inhibited responses to targets derived from the non-transposed root letters. This inhibition was found to be unrelated to the relative frequency of the original roots and the TL-roots. Experiment 2 replicated the results of Experiment 1 and provided an additional finding: if the transposed letters of the root created a nonsense-root that has no lexical representation, then neither inhibition nor facilitation was obtained. Finally, Experiment 3 demonstrated an identical pattern of results when primes consisted of nonwords, which were TL root derivations, rather then simply the TL root letters. In contrast to English, French, or Spanish, TL-primes do not facilitate recognition of targets, and depending on the lexical status of the root morpheme embedded in them, they can even produce inhibition.

The present paper joins a series of recent research reports which examined the impact of letter transpositions on reading (Grainger & van Heuven, 2003; Lupker & Perea, 2003a; Perea & Lupker, 2003b; Perea & Lupker, 2004; Schoonbaert & Grainger, 2004; Rayner, White, Johnson & Liversedge, 2006; Perea & Carreiras, 2006a; Perea & Carreiras, 2006b; Perea & Carreiras, 2008; Lupker, Perea, & Davis, 2008; Perea & Perez, 2009). Although these studies employed various experimental procedures such as masked priming, or the monitoring of eye movements, they reached similar conclusions: the print processing system is quite resilient to the transpositions of letters within a printed word. Thus, TL nonword primes were consistently found to facilitate recognition of word targets, relative to control conditions in which letters in the priming stimulus were replaced rather than transposed. Similarly, eye movements studies reported that unless beginning or end letters are transposed, or unless morphemic boundaries are crossed, letter transposition has little effect on measures of first fixation and gaze duration (e.g., Christianson, Johnson, & Rayner, 2005). The discovery that letter-transpositions have little effect on reading should not be under-estimated. It suggested important constraints on orthographic coding schemes for lexical search, thereby produced a new generation of computational models that did not rely on the traditional slot-based coding. However, one hidden assumption common to all of these models is that words in lexical space of alphabetic orthographies are aligned according to some orthographic principle, and that the sub-lexical units of the processing system somehow code the sequence of letters for lexical search.

The findings we report from Hebrew stand in sharp contrast to the studies conducted in Indo-European languages. The most comparable experiment is Experiment 3, since the stimuli and procedure of this experiment mimicked the masked priming manipulations reported in Indo-European languages. Similar to all of the above studies, primes were nonwords that were constructed by transposing two middle consonants in the targets. However, rather than obtaining facilitation relative to a control conditions in which letters are replaced, an inhibition was obtained when the transposition of letters created another root embedded in the nonword. Although we should exert some caution, given the weakness of the item analysis derived from our restricted number of items in Experiment 3, taken together, the three experiments do present a coherent picture, suggesting that the pattern of results in Hebrew diverges from that of English, French or Spanish. To our knowledge, this is the first inhibition demonstrated with TL masked primes. Note that even when transposing the letters did not create a recognizable root, no facilitation was found. This latter finding should not come as a surprise. Recently, Frost et al. (2005) found in a series of eight experiments that while masked morphological priming is robust in Hebrew, form-orthographic priming cannot be obtained. If simple orthographic priming cannot be revealed in Hebrew, primes consisting of transposed letters would not facilitate their related targets either. Experiments 1 and 2 basically demonstrated a pattern of results similar to that of Experiment 3. When the targets' root letters were transposed to create another root, TL root primes actually produced significant inhibition. When TL root primes were nonsense roots, neither facilitation nor inhibition was observed. We should note that the inhibition of TL-root primes was not modulated by factors such as root frequency; rather, it seems that this inhibition emerges from a competition between root units in lexical space.

One possible confound that should be considered while discussing letter-transposition effects in Hebrew is word length. On average, words in Hebrew are shorter than words in English, French, or Spanish, since some of the vowel information is missing in print, and it has been shown that TL priming effects are stronger with longer words (e.g., Grainger, 2008). The question at hand is whether the present findings from Hebrew can be attributed to that factor. There are several arguments against this suggestion. First, in Experiment 3 we employed words that were 5 to 7 letters long, and such words were shown to produce robust TL priming effects in languages such as Spanish or English (CANISO-CASINO, JUGDE-JUDGE). Moreover, a recent study in Japanese (Perea & Perez, 2009) demonstrated significant TL priming with words having but four moras. Hence, it seems that TL priming effects are not constrained to long words only. Finally, our results from Hebrew do not simply reveal reduced TL priming effects, they reveal patterns of inhibition. Note that none of the present models that account for TL priming in Indo-European languages constrains the effect to long words only, and none of these models can account for TL inhibition.

One possible caveat of our present design is that the nonwords were always formed of non-existing roots so that correct lexical decisions could have been generated by detection of a real root in the target stimulus. By this view, the performance of our subjects in the lexical decision task could have been shaped by a specific strategy of root extraction, induced by the structure of the nonwords. Although we cannot refute this possibility, we find it unlikely. First, previous studies have shown that root extraction is the primary target of word recognition also in the naming task and in eye-movement monitoring. Second, the results of Experiment 3 converge with our previous findings regarding effects on letter transposition using RSVP (Velan & Frost, 2007). Taken together, these two studies provide strong support for a lexical architecture in which the registering of exact order of root letters is necessary for lexical access.

Our findings converge with the recent study of Velan and Frost (2007) that examined Hebrew-English bilinguals using RSVP. Velan and Frost showed that while transpositions did not affect the rapid reading of sentences in English, it had a huge effect in Hebrew. Our findings also converge with recent reports by Friedmann and her colleagues showing that effects of letter-position dyslexia are significantly different for Hebrew and English materials (Friedmann & Gvion, 2001; Friedmann & Gvion 2005). Friedmann reported two cases of Hebrew-speaking acquired-dyslexia patients who had intact letter identification and intact binding of letters to words but a deficit in encoding the position of each letter within the word. Since in Hebrew, in contrast to English, most errors in letter position would in most probability form a legal sequence in an existing word, these patients had significant difficulties in reading Hebrew.

This brings us to the main conclusion of our investigation. Although Hebrew is an alphabetic orthography like English or French, words in Hebrew lexical space are not organized simply according to their orthographic structure, and reading does entails more than just the registering of letter sequences for lexical search. Rather, words are organized according to root families, and the target of lexical search is a root morpheme. Thus, reading in a Semitic language such as Hebrew requires extensive prelexical morphological processing. The extraction of a root morpheme from the orthographic input is an early process that governs lexical search. Support for this hypothesis also comes from a variety of results obtained in Hebrew and in English when a morphological manipulation is employed in the parafovea. Whereas there is ample evidence that the root morpheme is already extracted parafoveally leading to a significant parafoveal preview benefit (e.g., Deutsch et al., 2000; Deutsch et al., 2003), parallel studies in English seem to suggest that morphological processing in the parafovea does not influence eye-movements (Rayner et al., 2006). Our conclusions regarding the differences in processing Semitic and non-Semitic languages are further supported by recent finding in our laboratory suggesting that the minority of Hebrew words that do not have an underlying Semitic structure and are not derived from productive roots [3] show transposition effects as well as form-priming effects similar to that of English or Spanish (Frost & Velan, 2008). In this study we found that readers of Hebrew treat Semitic words and non-Semitic words very differently. Whereas Semitic words are always processed by extracting their root first, words that were imported into Hebrew from foreign languages such as Greek or Latin are processed by considering their entire letter sequence, similar to English or French.

How can we model the findings from Hebrew? The question at hand is what type of lexical architecture would, on the one hand, generate the consistent effects of root priming (Frost et al., 1997; Frost et al., 2000), and on the other hand, produce no form priming (Frost et al., 2005), as well as an intolerance to letter-transpositions (Velan & Frost, 2007; Frost, in press). Considering a localist interactive activation approach, it seems that any model of reading Hebrew would have to implement a layer of morphemic units which mediates the activation between letter units and word units, at least for those words in Hebrew which are root-derived. A similar conclusion was reached by Velan, Frost, & Plaut (2005), who argued that a Parallel-Distributed-Processing model of Hebrew would necessarily need to implement root-morpheme units in order to produce the set of root-priming effects obtained in Semitic languages. The model architecture would then consist of a tripartite structure where letter units simultaneously map into word units and into tri-literal [4] orthographic units that represent all of the existing roots in the language (about 3000). These root units would be linked to the word units which represent all of the permissible inflections and derivations of a given root. Borrowing the terms of resonance theory (e.g., Van Orden & Goldinger, 1994), word recognition in Hebrew reflects a resonance between root units and word units, which are simultaneously activated by the printed input. Note that this architecture is qualitatively different from the one we originally proposed for Hebrew (Frost et al., 1997, Deutsch et al., 1998) in that activation of word units is not only aided but *necessarily* mediated by root units. In this respect, we propose here a model of reading Hebrew that is primarily morphologically driven, rather than orthographically driven.

Considering the network structure of such a model, the main constraint on the possible links between letters and root units is that the orthographic coding of roots would require letter

[3]A subset of words in Hebrew does not follow the classical structure of Semitic languages as they infiltrated Hebrew from non-Semitic languages throughout history.

[4]Or bipartite structures (which contain only 2 consonantal roots) for mute and defective roots (Velan et al., 2005).

location to be precise, so that there is a rigid relative position coding to activate the three letters that compose a given root. By this view, the system would not allow for any letter-position noise as the overlap model does (Gomez et al., 2008), and units such as open bigrams that do not contain precise information about which root letter precedes which, would not be part of the mapping system.

What remains to be discussed is the parsing mechanism. Since the letters of the root and the word patterns are intertwined, the question at hand is how are root letters extracted from the visual input to activate a given root unit in the morphemic layer. The answer is most probably related to the highly predictable distribution of letters belonging to the root or the word-pattern in Semitic languages. Although roots can begin with any letter, most word-patterns begin with the letters H, M, T, or N. Some letters like D, G, K or S never belong to any word-pattern and always belong to the root. If the second letter of the word belongs to the pattern then there is a high probability that it is a T, etc. In other words, the distribution of the letters in Hebrew in different positions in the word functions as a primary clue in indicating the position of the root letters relative to the word-pattern letters. But note again that the cues regarding which letters belong to the root and which belong to the word pattern are heavily dependent on precise letter-by-slot coding. Thus, any algorithm that allows a fast prelexical morphological decomposition in Hebrew would require very rigid letter position mapping. It is in the present context that it becomes clear why models like SOLAR or SERIOL could work well for English, French, or Spanish, but not for Hebrew. Words in Hebrew have an internal structure, and this structure dictates the sequence of letters. The early stages of speech or print recognition are aimed at recovering this internal structure. Hence, orthographic units such as open bigrams, for example, do not reveal or capture the main mechanism that forms words in Semitic languages. These units were invoked to model reading in languages in which aside of affixes, the sequence of letters does not represent any internal structure. It is also clear why Hebrew words that do not have a Semitic structure are processed like English words (Frost & Velan, 2008). Non-Semitic Hebrew words do not have the typical internal structure that allows a fast morphological decomposition. Hence, it seems that such words are organized separately in lexical space.

This brings us to the second possible constraint, which concerns the strength of inhibitory and excitatory connections between root units and word units. It has been argued quite convincingly that some letter position noise must exist at lower levels of letter processing, as a certain amount of uncertainty regarding letter position is a property of the perceptual system (see Gomez, Ratcliff & Perea, 2008, for a discussion). Since the order of root letters is critical for correct word identification in Hebrew, the system must be set to reduce the detrimental impact of such inevitable noise to a minimum. In order to avoid lexical substitutions originating from roots that share an identical set of letters, the model would need to implement strong inhibitory connections between these root units, and between all of their respective inflections and derivations. Thus, **s.l.x** for example, would exert a much stronger inhibition on **l.x.s, x.s.l, x.l.s**., and their derivations, relative to **s.l.t**, or **l.x.m**. This architecture can easily account for the inhibition we obtained for TL-roots relative to the control roots that did not contain the precise set of root letters, but had one letter that was different.

In conclusion, the present study provides important evidence regarding the differences in processing print in a Semitic Language such as Hebrew relative to Indo-European languages such as English. The impact of letter transposition on reading seems to suggest that lexical space in alphabetic orthographies may be structured very differently in different languages if their morphological structure diverges qualitatively.

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Appendix A

The Hebrew Alphabet

Hebrew Print	Orthographic Transcription	Phonetic Transcription
א	ʔ	ʔ
ב	b	b / v
ג	g	g
ד	d	d
ה	h	h
ו	w	o / u / v
ז	z	z
ח	x	x
ט	θ	t
י	y	i / y
כ	k	k / x
[a]ך	K	x
ל	l	l
מ	m	m
[a]ם	M	m
נ	n	n
[a]ן	N	n
ס	S	s
ע	ς	ʔ
פ	p	p / f
[a]ף	P	f
צ	c	c
[a]ץ	C	c
ק	q	k
ר	r	r
ש	s	s / ʃ
ת	t	t

[a]The letters q, m, n, p and c have different orthographic forms when they appear at the end of the word.

Appendix B

Stimuli used in Experiment 1

Target			Root		TL root		Control	
Hedrew	**Ortho. trans.**	**Phonetic trans.**	**Hebrew**	**Ortho. trans.**	**Hebrew**	**Ortho. trans.**	**Hebrew**	**Ortho. trans.**
			Root freq higher than TL freq					
אגודל	ʔgwdl	/ʔagudal/	גדל	gdl	דגל	dgl	אגל	ʔgl
פלישה	plysh	/pliʃa/	פלש	pls	פשל	psl	פשה	psh
מסורת	mSwrt	/masoret/	מסר	mSr	סמר	Smr	מרת	mrt
סמכות	Smkwt	/samxut/	סמכ	smk	מסכ	msk	מכת	mkt
עמידות	ɕmydwt	/ʔamidut/	עמד	ɕmd	מעד	mɕd	מדת	mdt
קולטן	qwlθN	/koltan/	קלט	qlθ	קטל	qθl	לטנ	lθn
תלבושת	tlbwst	/tilboʃet/	לבש	lbs	בלש	bls	תלש	tls
חשבהבמ	mxsbh	/maxʃava/	חשב	xsb	חבש	xbs	מחב	mxb
סקירה	Sqyrh	/skira/	סקר	Sqr	סרק	Srq	סקה	Sqh
לחימה	lxymh	/lexima/	לחמ	lxm	חלמ	xlm	למה	lmh
מצבר	mcbr	/macber/	צבר	cbr	צרב	crb	מצר	mcr
ניצחון	nycxwN	/nicaxon/	נצח	ncx	צנח	cnx	נחנ	nxn
רציחה	rcyxh	/recixa/	רצח	rcx	צרח	crx	ריח	ryx
אספקה	ʔSpqh	/ʔaspaka/	ספק	Spq	פסק	pSq	אפק	ʔpq
תקציר	tqcyr	/takcir/	קצר	qcr	קרצ	qrc	תקר	tqr
קליפה	qlyph	/klipa/	קלפ	qlp	קפל	qpl	קלה	qlh
תחביר	txbyr	/taxbir/	חבר	xbr	בחר	bxr	תחב	txb
חולשה	xwlsh	/xulʃa/	חלש	xls	לחש	lxs	חוש	xws
			Root freq lower than TL freq					
קיפוח	qypwx	/kipuʔax/	קפח	qpx	פקח	pqx	קיפ	qyp
הסחפות	hSxpwt	/hisaxfut/	סחפ	Sxp	ספח	Spx	סחת	Sxt
בידור	bydwr	/bidur/	בדר	bdr	דבר	dbr	דור	dwr
דפיקה	dpyqh	/dfika/	פדק	dfq	פקד	pqd	דפה	dph
פשיטה	psyθh	/pʃita/	פשט	psθ	שפט	spθ	פטה	pθh
חשדנות	xsdnwt	/xaʃdanut/	חשד	xsd	חדש	xds	שדנ	sdn
הכרזה	hkrzh	/haxraza/	כרז	krz	רכז	rkz	הכר	hkr
פיחות	pyxwt	/pixut/	פחת	pxt	פתח	ptx	פיח	pyx
גירוד	gyrwd	/girud/	גרז	grd	דרג	drg	ורד	rwd
חרוז	xrwz	/xaruz/	חרז	xrz	חזר	xzr	חוז	xwz
חיסור	xySwr	/xisur/	חסר	xSr	סחר	Sxr	חור	xwr
מסרגה	mSrgh	/masrega/	סרג	Srg	סגר	Sgr	מרג	mrg
קבורה	qbwrh	/kvura/	קבר	qbr	בקר	bqr	ברה	brh
הקצפה	hqcph	/hakcafa/	קפד	qcp	קפצ	qpc	צפה	cph
ריפוד	rypwd	/ripud/	רפד	rpd	רדפ	rdp	ריד	ryd
תפירה	tpyrh	/tfira/	תפר	tpr	פתר	ptr	פרה	prh
מברגה	mbrgh	/mavrega/	ברג	brg	בגר	bgr	מבג	mbg
זרימה	zrymh	/zrima/	זרמ	zrm	זמר	zmr	רמה	rmh

Appendix C

Stimuli used in Experiment 2

Target			Root		TL existing root		TL nonsense root		Control	
Hebrew	Ortho. trans.	Phonetic trans.	Hebrew	Ortho.trans.	Hebrew	Ortho. trans.	Hebrew	Ortho. trans.	Hebrew	Orth
מדרגה	mdrgh	/madrega/	דרג	drg	גרד	grd	רדג	rdg	מרג	
פיקדון	pygdwN	/pikadon/	פקד	pqd	דפק	dpq	פדק	pdq	קונ	
החזרה	hxzrh	/haxzara/	חזר	xzr	חרז	xrz	זחר	zxr	החר	
רכזייה	mrkzyyh	/merkaziya/	רכז	rkz	כרז	krz	רזכ	rzk	מכז	
חדשנות	xdsnwt	/xadʃanut/	חדש	xds	חשד	xsd	דחש	dxs	דשנ	
עמידות	ςmydwt	/ʔamidut/	עמד	ςmd	מעד	mςd	עדמ	ςdm	עדת	
מסגרת	msgrt	/misgeret/	סגר	Sgr	סרג	Srg	גסר	gSr	מגר	
לחימה	lxymh	/lexima/	לחמ	lxm	חלמ	xlm	למח	lmx	חמה	
סקירה	Sqyrh	/skira/	סקר	Sqr	סרק	Srq	קסר	qSr	סקי	
פלישה	plysh	/pliʃa/	פלש	pls	פשל	psl	לפש	lps	פשה	
לחישה	lxysh	/lexiʃa/	לחש	lxs	חלש	xls	לשח	lsx	חיש	
צריבה	crybh	/criva/	צרב	crb	צבר	cbr	רצב	rcb	צבה	
תלבושת	tlbwst	/tilboʃet/	לבש	lbs	בלש	bls	לשב	lsb	לשת	
התקפלות	htqplwt	/hitkaplut/	קפל	qpl	קלפ	qlp	פקל	pql	קפת	
מקפצה	mqpch	/makpeca/	קפצ	qpc	קצפ	qcp	פקצ	pqc	מקצ	
תקציר	tqcyr	/takcir/	קצר	qcr	קרצ	qrc	צקר	cqr	תקר	
מרדף	mrdP	/mirdaf/	רדפ	rdp	רפד	rpd	דרפ	drp	מדפ	
מחשבה	mxsbh	/maxʃava/	חשב	xsb	חבש	xbs	שחב	sxb	מחב	
קיפוח	qypwx	/kipuʔax/	קפח	qpx	פקח	pqx	קחפ	qxp	קיפ	
הדברות	hdbrwt	/hidabrut/	דבר	dbr	בדר	bdr	דרב	drb	דרת	
פשיטה	psyθh	/pʃita/	פשט	psθ	שפט	spθ	פטש	pθs	פטה	
פיתרון	pytrwN	/pitaron/	פתר	ptr	תפר	tpr	תרפ	trp	תרנ	
זרימה	Zrymh	/zrima/	זרמ	zrm	זמר	zmr	רזמ	rzm	רמה	
אליפות	ʔlypwt	/ʔalifut/	אלפ	ʔlp	אפל	ʔpl	פאל	pʔl	אלת	
הדבקה	hdbqh	/hadbaka/	דבק	dbq	בדק	bdq	דקב	dqb	דקה	
ביטחון	byθxwN	/bitaxon/	בטח	bθx	טבח	θbx	בחט	bxθ	ביח	
בליעה	blyςh	/bliʔa/	בלע	blς	בעל	bςl	לבע	lbς	לעה	
תעבורה	tςbwrh	/taʔabura/	עבר	ςbr	בער	bςr	ברע	brς	עור	
בריחה	bryxh	/brixa/	ברח	brx	בחר	bxr	רבח	rcx	ברה	
ביקורה	byqwrt	/bikoret/	בקר	bqr	ברק	brq	רבק	rbq	ברת	
הרגשה	hrgsh	/hargaʃa/	רגש	rgs	גרש	grs	רשג	rsg	גשה	
גמישות	gmyswt	/gmiʃut/	גמש	gms	גשמ	gsm	מגש	mgs	משת	
זיקנה	zyqnh	/zikna/	זקנ	zqn	זנק	znq	קזנ	qzn	קנה	
זריקה	zrykh	/zrika/	זרק	zrq	זקר	zqr	רזק	rzq	זקה	
חדירה	xdyrh	/xadira/	חדר	xdr	חרד	xrd	דחר	dxr	חרה	
לחיצה	lxych	/lexica/	לחצ	lxc	חלצ	xlc	לצח	lcx	ליצ	
הדגמה	hdgmh	/hdgama/	דגמ	dgm	גדמ	gdm	דמג	dmg	גמה	
חליבה	xlybh	/xaliva/	חלב	xlb	חבל	xbl	לחב	lxb	לבה	

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Target			Root		TL existing root		TL nonsense root		Control	
Hebrew	Ortho. trans.	Phonetic trans.	Hebrew	Ortho.trans.	Hebrew	Ortho. trans.	Hebrew	Ortho. trans.	Hebrew	Orth
חומצה	xwmch	/xumca/	חמצ	xmc	מחצ	mxc	חצמ	xcm	חומ	
סליחה	Slyxh	/slixa/	סלח	Slx	חסל	xSl	לסח	lSx	סחה	
חקירה	xqyrh	/xakira/	חקר	xqr	חרק	xrq	קחר	qxr	חקה	
רחמנוה	rxmnwt	/raxmanut/	רחמ	rxm	חרמ	xrm	רמח	rmx	חמנ	
חתימה	xtymh	/xatima/	חתמ	xtm	תחמ	txm	חמת	xmt	תימ	
טבילה	tbylh	/tvila/	טבל	θbl	בטל	bθl	טלב	θlb	טלה	
טינופה	θynwpt	/tinofet/	טנפ	θnp	נטפ	nθp	טפנ	θpn	טפת	
כישלון	kyslwN	/kiʃalon/	כשל	ksl	שכל	skl	כלש	kls	שלנ	
הכשרה	hksrh	/haxʃara/	כשר	ksr	שכר	skr	כרש	krs	כשה	
הנחתה	hnxth	/hanxata/	נחת	nxt	נתח	ntx	חנת	xnt	חתה	

Appendix D

Stimuli used in Experiment 3

Target			TL existing root		TL nonsense root		Control	
Hebrew	Ortho. trans.	Phonetic tans.	Hebrew	Ortho. trans.	Hebrew	Ortho. trans.	Hebrew	Ortho. trans.
מדבקה	mdbqh	/madbeka/	מבדקה	mbdqh	מדקבה	mdqbh	מזלקה	mzlqh
מחשבה	mxsvh	/maxʃava/	מחבשה	mxbsh	משחבה	msxbh	מחדמה	mxdmh
הבטחה	hdθxh	/havtaxa/	הטבחה	hθbxh	הבחטה	hbxθh	הבלזה	hblzh
הבקעה	hbqçh	/havkaʔa/	הקבעה	hqbçh	הבעקה	hbçqh	החלעה	hxlçh
הברחה	hvrxh	/havraxa/	הבחרה	hbxrh	הרבחה	hrbxh	הבלדה	hbldh
הדברה	hdbrh	/hadbara/	הבדרה	hbdrh	הדרבה	hdrbh	הנבסה	hnbSh
הזרקה	hzrqh	/hazraka/	הזקרה	hzqrh	הרזקה	hrzqh	הדמקה	hdmqh
הזרמה	hzrmh	/hazrama/	הזמרה	hzmrh	הרזמה	hrzmh	הזכלה	hzklh
החדרה	hxdrh	/haxdara/	החרדה	hxrdh	הדחרה	hdxrh	השדמה	hsdmh
מחלבה	mxlbh	/maxleva/	מחבלה	mxblh	מלחבה	mlxbh	מנטבה	mnθbh
התחמקות	htxmqwt	/hitxamkut/	התמחקות	htmxqwt	התחקמות	htxqmwt	התחלגות	htxlgwt
החתמה	hxtmh	/haxtama/	התחמה	htxmh	החמתה	hxmth	הרתשה	hrtsh
הכרזה	hkrzh	/haxraza/	הרכזה	hrkzh	הכזרה	hkzrh	המפזה	hmpzh
הכתרה	hktrh	/haxtara/	הכרתה	hkrth	התכרה	htkrh	הכסעה	hkSçh
הלבשה	hlbsh	/halbaʃa/	הבלשה	hblsh	הלשבה	hlsbh	הדבחה	hdbxh
מלחמה	mlxmh	/milxama/	מחלמה	mxlmh	מלמחה	mlmxh	משרמה	msrmh
התלחשות	htlxswt	/hitlaxʃut/	התחלשות	htxlswt	התלשחות	htlsxwt	התרחגות	htrxgwt
הנמקה	hnmqh	/hanmaka/	הנקמה	hnqmh	המנקה	hmnqh	הנצתה	hncth
הנפשה	hnpsh	/hanfaʃa/	הנשפה	hnsph	הפנשה	hpnsh	הצבשה	hcbsh
מסגרת	mSgrt	/misgeret/	מסרגת	mSrgt	מגסרת	mgSrt	מפגדת	mpgdt
מסרטה	mSrθh	/masreta/	מסטרה	mSθrh	מרסטה	mrSθh	מסננה	mSnqh
התעעגות	htçngwt	/hitʔangut/	התעגנות	htçgnwt	התנעגות	htnçgwt	התמאגות	htmʔgwt
העלמות	hçlmwt	/hitʔalmut/	העמלות	hçmlwt	הלעמות	hlçmwt	התלפות	htlpwt

Target			TL existing root		TL nonsense root		Control	
Hebrew	Ortho. trans.	Phonetic tans.	Hebrew	Ortho. trans.	Hebrew	Ortho. trans.	Hebrew	Ortho. trans.
התעצלות	htςclwt	/hitʔaclut/	התעלצות	htςlcwt	התצעלות	htcςlwt	התעמגות	htςmgwt
התעקשות	htςqswt	/hitʔakʃut/	התעשקות	htςsqwt	התקעשות	htqςswt	התלגשות	htlgswt
הפחתה	hpxth	/hafxata/	הפתחה	hptxh	החפתה	hxpth	הסחקה	hSxqh
מפקדה	mpqdh	/mifkada/	מקפדה	mqpdh	מפדקה	mpdqh	מפגחה	mpgxh
הפקרות	hpqrwt	/hefkerut/	הפרקות	hprqwt	הקפרות	hqprwt	הדערות	vdςrwt
הפרעה	hprςh	/hafraʔa/	הפערה	hpςrh	הרפעה	hrpςh	הקרתה	hqrth
התפרצות	htprcwt	/hitparcut/	התפצרות	htpcrwt	התרפצות	htrpcwt	התפקבות	htpqbwt
הפשטה	hpsθh	/hafʃata/	השפטה	hspθh	הפטשה	hpθsh	המכטה	hmkθh
התפתלות	htptlwt	/hitpatlut/	התתפלות	httplwt	התפלתות	htpltwt	התחתקות	htxtqwt
מקפצה	mqpch	/makpeca/	מקצפה	mqcph	מפקקה	mpqch	מקרה	mqrgh
התקצרות	htqcrwt	/hitkacrut/	התקרצות	htqrcwt	התצקרות	htcqrwt	התגחרות	htgxrwt
מרגמה	mrgmh	/margema/	מגרמה	mgrmh	מרמגה	mrmgh	מבגשה	mbgsh
הרגשה	hrgsh	/hargʃa/	הגרשה	hgrsh	הרשגה	hrsgh	הרחסה	hrxSh
מחצבה	mxcbh	/maxceva/	מחבצה	mxbch	מצחבה	mcxbh	משקבה	msqbh
הטבלה	hθblh	/hatbala/	הבטלה	hbθlh	הטלבה	hθlbh	הגבדה	hgbdh
הנחתה	hnxth	/hanxata/	הנתחה	hntxh	החנתה	hxnth	הנדשה	hndsh
הדגשה	hdgsh	/hadgaʃa/	הגדשה	hgdsh	הדשגה	hdsgh	המכשה	hmksh

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Table 1

Examples of the Stimuli Used In Experiment 1

	Root freq higher than TL freq			Root freq lower than TL freq		
	Root	**TL root**	**Control**	**Root**	**TL root**	**Control**
Mask	#######	#######	#######	#######	#######	#######
Prime						
Ortho. trans.	xsb	xbs	mxb	brg	bgr	mbg
Hebrew	חשב	חבש	מחב	ברג	בגר	מבג
Target						
Ortho. trans.	mxsbh	mxsbh	mxsbh	mbrgh	mbrgh	mbrgh
Hebrew	מחשבה	מחשבה	מחשבה	מברגה	מברגה	מברגה
Phon. trans.	/maxʃava/			/mavrega/		
Meaning	“thought”			“electric screwdriver”		

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Table 2

Mean Reaction Times (ms), Percent Errors and Priming Effects for Lexical Decision to Target Words and Nonwords in Experiment 1

	Words					
	Root freq higher than TL freq			**Root freq lower than TL freq**		
	Root	**TL-root**	**Control**	**Root**	**TL-root**	**Control**
RT	541	576	562	560	588	578
Error	6.2%	7.5%	9.2%	4.6%	10.8%	9.8%
Priming	+21	-14		+18	-10	

Nonwords			
	Root	TL-root	Control
RT	632	633	636
Error	9.2%	6.4%	6.9%
Priming	4	3	

$^{*}p < .05$

Table 3

Examples of the Stimuli Used in Experiment 2

	Root	TL existing root	TL nonsense root	Control
Mask	#######	#######	#######	#######
Prime				
Ortho. trans.	dbk	bdk	dkb	dkh
Hebrew	דבק	בדק	דקב	דקה
Target				
Ortho. trans.	hdbkh	hdbkh	hdbkh	hdbkh
Hebrew	הדבקה	הדבקה	הדבקה	הדבקה
Phon. trans.	/hadbaka/			
Meaning	“gluing”			

Table 4

Mean Reaction Times (ms), Percent Errors And Priming Effects for Lexical Decision in Experiment 2

	Root	**TL existing root**	**TL nonsense root**	**Control**
		Words		
RT	518	546	539	537
Error	3.0%	7.5%	7.9%	4.8%
Priming	+19*	-9*	-2	
		Nonwords		
RT	589	585	581	589
Error	7.2%	5.5%	4.3%	4.8%
Priming	0	4	8	

* $p < .05$

Table 5

Examples of the Stimuli Used in Experiment 3

	Root	**TL existing root**	**TL nonsense root**	**Control**
Mask	#######	#######	#######	#######
Prime				
Ortho. trans.	hbθxh	hθbxh	hbxθh	hblzh
Root	(bθx)	(θbx)	(bxθ)	(blz)
Hebrew	הבטחה	הטבחה	הבחטה	הבלזה
Target				
Ortho. trans.	hbθxh	hbθxh	hbθxh	hbθxh
Hebrew	הבטחה	הבטחה	הבטחה	הבטחה
Phon. trans.	/ havtaxa /			
Meaning	“Promise”			

Table 6

Mean Reaction times (ms), percent errors and priming effects for lexical decision to target words and nonwords in Experiment 3

	Root	TL existing root	TL nonsense root	Control
		Words		
RT	523	572	558	561
Error	2.5%	7.0%	6.0%	7.0%
Priming	+29*	-11*	+3	
		Nonwords		
RT	597	595	595	595
Error	7.4%	6.0%	5.0%	4.6%
Priming	-2	0	0	

* $p < .05$