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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.

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., Elman, 2004; Harm, McCandliss, & Seidenberg, 2003; Harm & Seidenberg, 2004; Rueckl, 2002). 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, 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., Elman, 2004; Rueckl, 2002; 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.

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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∫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**C$_1$C$_2$**o**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**C$_1$C$_2$**o**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**C$_1$C$_2$**o**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 (Deutsch, Frost, & Forster, 1998; Deutsch, Frost, Peleg, Pollatsek, & Rayner, 2003; Deutsch, Frost, Pollatsek, & Rayner, 2000, 2005; Feldman, Frost, & Pnini, 1995; Frost, Deutsch, & Forster, 2000; Frost, Deutsch, Gilboa, Tannenbaum, & Marslen-Wilson, 2000; Frost, Forster, & Deutsch, 1997; Frost et al., 2005; Velan, Frost, Deutsch, & Plaut, 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., Deutsch et al., 1998; Frost et al., 1997). 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**∫o**r**et/-/**k**i∫u**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, 2009).

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, 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