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12 Reading in Hebrew Versus Reading in English

Is There a Qualitative Difference?

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To rapidly perceive, recognize, and process printed words, some well-defined organization of word units must exist in the mental lexicon. Models of visual word recognition are concerned with the principles of this organization. For example, the entry-opening model (Forster, 1999; Forster & Davis, 1984) assumes that lexical entries are organized into bins based on their orthographic form. Thus, words sharing similar letter sequences (or orthographic neighbors) would be located in the same bin. Upon presentation of a printed word, the orthographic properties of the input are used to calculate an approximate address (i.e., a bin number), and a frequency-ordered search within that bin is performed to locate the matching entry. Alternatively, attractor-based models of reading (e.g., Rueckl, 2002) assume that printed words are represented as points in a perceptual space that is defined in terms of orthographic properties. Words that are close together in this perceptual space will tend to overlap in their orthographic structure. The process of word recognition is then described in terms of a trajectory of the system through its state space, where 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. Each word has a unique attractor, and the positions of the attractors in the state space are organized to reflect similarities in spelling.

The present chapter is concerned with the following question: Could there be *qualitative* differences in the principles of lexical organization and lexical processing in different alphabetic orthographies? Within this context, two contrasting theoretical approaches can be outlined. What I will label here as the *universal view* suggests that similar principles of lexical organization and processing apply to different languages. Obviously, languages with alphabetic orthographies may differ in their statistical properties (i.e., number of words, word length, distributional properties of sublinguistic units such as bigrams and trigrams, etc.). However, these differences are quantitative in nature, and, hence, the resulting processing differences will be quantitative as well. The universal view is best represented by current parallel-distributed processing models of word recognition that focus on statistical learning and the search for orthographic regularities in the printed input (e.g., Seidenberg, McDonald, & Safran, 2003). In contrast, what I label here as the *structural-ecological view* suggests that the principles of organization and processing of words in alphabetic orthographies are not determined exclusively by orthographic constraints but may be shaped by the language's morphological characteristics. According to the structural-ecological view, reading entails not only the unequivocal recognition of a letter string, but also an efficient on-line process of morphological and semantic analysis. Hence, reading processes in two languages that have very different morphological structures may differ qualitatively, even if they employ similar orthographic systems (e.g., Frost, Kugler, Deutsch, & Forster, 2005).

How would we know that cross-linguistic processing differences are qualitative rather than quantitative? Admittedly, this is a tough question. Since the distributional properties of words and sublinguistic orthographic and phonological units differ from language to language, some processing differences are necessarily expected. A convincing case for qualitative cross-linguistic differences would be established, therefore, only by finding points of discontinuity, where patterns of performance in one language are opposed to the patterns found in another language, and by demonstrating converging results from several research paradigms. Obviously, the most convincing case would be made by bilingual experiments in which very similar linguistic manipulations are used on identical subjects, producing different patterns of results. The aim of the present chapter is to argue for the ecological-structural view by examining two languages: Hebrew and English. Both have an alphabetic orthography, but they differ in their morphological structure. The following review and discussion will demonstrate that reading processes in these languages are qualitatively different. This will be done by assembling evidence from masked orthographic priming, masked morphological priming, the measurement of parafoveal preview benefits, and by monitoring the impact of letter transposition. Finally, converging evidence from reading disorders will be discussed as well. I will first begin with a brief description of the orthographic and morphological characteristics of the two languages.

HEBREW AND ENGLISH: ORTHOGRAPHIC STRUCTURE VERSUS MORPHOLOGICAL STRUCTURE

Hebrew and English are both considered deep alphabetic orthographies, where letters represent phonemes, but the mapping of graphemes-to-phonemes is not entirely transparent (Frost, Katz, & Bentin, 1987; Katz & Frost, 1992). Yet, whereas the English alphabet has 26 letters, the Hebrew alphabet consists of only 22 letters, which mostly represent consonants. Hebrew vowels can optionally be superimposed on the consonants as diacritical marks ("points"); in addition, some vowels may also be represented by letters, depending on the orthographic or phonological context. Since different vowels may be inserted into the same string of consonants to form different words or nonwords, Hebrew unpointed print cannot specify a unique phonological unit, and a printed consonant string is phonologically ambiguous, often representing more than one word. Thus, the depth of the Hebrew orthography is different by nature from that of English orthography. Whereas in English the opaque relations of spelling to sound are related to the *inconsistency* of letter clusters, in Hebrew, opaque spelling-to-sound connections arise simply from *missing* phonemic information, mainly vowel information. Extensive research has consistently revealed that in contrast to English, reading in Hebrew involves interplay of two computational processes that are defined by the size of the computed units. The first process is characterized by the conversion of units of single letters into consonantal information (Frost, 1994, 1995). This process provides an impoverished phonological representation that is often sufficient for lexical access (Frost, 1998). However, a detailed and complete phonological representation that is necessary for reading is produced by using morphological information. As will be explained later, this morphological information provides the cluster of all missing vowels as one morphemic unit: the *word pattern* (see Frost, 2006, for a discussion).

The main difference between Hebrew and English thus concerns their morphological structure. The morphological structure of Indo-European languages can be characterized by a linear and sequential concatenation of morphemic units to form multimorphemic words. Thus, both inflectional and derivational morphology are based on appending prefixes or suffixes to a base morpheme. As a general rule, the orthographic integrity of the base form remains intact, and, in fact, in most languages with concatenated morphology, the base forms function not only as morphemes in complex forms but also constitute free word-forms in their own right (such as *dark* in *darkness,* or *dream* in *dreamer*).

Hebrew, on the other hand, is a Semitic language. Hence, most words can be decomposed into two abstract morphemes: the root and the word pattern. Roots in most cases consist of three consonants whereas word patterns can be either a sequence of vowels or a sequence consisting of both vowels and consonants. However, the most salient feature of Semitic languages' morphology concerns the special manner in which these morphemic units are combined to form morphological complexity. Roots and word patterns are not appended to one another linearly, as in languages with concatenated morphology. Rather, the consonants of the root are intertwined with the phonemes (and, therefore, the corresponding letters) of the word pattern. Unlike base forms in English, roots and word patterns are abstract structures because only their joint combination results in specific phonemic word-forms with specific meanings. These meanings cannot necessarily be predicted by analyzing each of the two morphemes independently. For example, the Hebrew word TIZMORET ("orchestra") is a derivation of the root ZMR. This root is mounted onto the phonological pattern TI--O-ET (each dash indicates the position of a root consonant). The root ZMR alludes to anything related to the concept of singing, and the phonological pattern TI--O-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 "orchestra." 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 singing. Other roots may also be combined with the word pattern TI--O-ET to form various feminine nouns. For example, the root LBŠ (conveying the action of dressing) can be combined with TI--O-ET, to form the word TILBOŠET ("an outfit"). Similarly, the word ZAMAR ("a singer") is formed by combining the root ZMR with the phonologic pattern -A-A-, which carries the information that the word is a noun that signifies a profession.

The two basic morphemic units in Hebrew (the root and the word pattern) differ in their linguistic characteristics. Whereas word patterns, at least in the nominal system, convey primarily vague grammatical information about word class (there are more than a hundred such patterns), the root carries the core meaning of the word. Given the important role of the root morpheme in forming word structure and word meaning, word recognition studies explore the possibility that the root plays a significant role in lexical organization. Indeed, numerous experiments that examined visual word recognition in Hebrew showed that root primes facilitate both lexical decision and the naming of target words that are derived from these roots. These findings suggested that in the course of word recognition, words are decomposed into their constituent morphemes and root units are the target of lexical search (e.g., Frost, Deutsch, & Forster, 2000; Frost, Deutsch, Gilboa, Tannenbaum, & Marslen-Wilson, 2000; Frost, Forster, & Deutsch, 1997). In a recent study, Frost et al. (2005) have consequently argued that the lexical architecture of Hebrew is primarily determined by morphological rather than by orthographic characteristics. According to this view, lexical space in Hebrew is organized so that all words derived from the same root are clustered together; therefore, the initial stage of word recognition entails the extraction of the root letters. This theoretical claim is in accordance with the structural-ecological view, as it suggests that the principle of organization and processing of words in alphabetic orthographies is primarily determined by the language's morphological characteristics. In Semitic languages, lexical neighborhoods are, thus, defined by root units and not by simple orthographic structure. Hence, whereas in English two words that share all of their letters but one are considered to be neighbors (e.g., Coltheart, Davelaar, Jonasson, & Besner, 1977), in Hebrew such words would be far apart in lexical space if they share a different root. The question at hand is whether the results obtained in visual word recognition in Hebrew are qualitatively different from those obtained in English. The following sections will review the empirical evidence for this claim.

THE EFFECT OF PRIME–TARGET ORTHOGRAPHIC OVERLAP

The most promising method for studying the properties of lexical space is to use a priming paradigm with very short exposure duration (masked priming). Considering, for example, attractor-based models, their basic account of facilitation is that for any prime–target pair, if the properties of the prime overlap with those of the target, then they must be "near" each other. Hence, moving toward the rhyme location will also involve moving towards the target location. When the prime is replaced by the target, the starting point for the new trajectory will be closer to the final destination than if the prime had been unrelated to the target, and, consequently, target recognition latencies are shorter in the related condition than in the unrelated one. In interactive activation models, it is assumed that words that are located in adjacent regions of lexical space somehow interact, so that activation of the central correlates of one word has an effect on the central correlates of the other words. The very nature of the access architecture in parallel activation models guarantees that through *cross-activation* the input stimulus will activate (or suppress) a wide range of word units to varying degrees, depending on the amount of orthographic overlap. Finally, in search models such as the entry-opening model, priming reflects a transfer effect. The results of processing carried out on the prime are transferred across to the target. In other words, most of the processing operations involved in analyzing the prime can serve for the identification and recognition of the target, resulting in a gain of processing time. This transfer is made possible when the primes and targets have overlapping orthographic structures. The theoretical question is, therefore, by what principle are words positioned one next to the other or by what principles are they interconnected. The definition adopted by most researchers in visual word recognition is that two words are considered as neighbors if they have a similar orthographic structure; for example, if they are of the same length but differ by a single letter (e.g., *face* and *race*; Coltheart et al. 1977), or if they share the body (the vowel plus the following consonants of the first syllable; Ziegler & Perry, 1998).

The empirical support for the claim that words are lexically organized by a principle of letter-sequence similarity comes from masked priming experiments in which primes and targets have a similar orthographic structure (i.e., form priming). The magnitude of the priming effect and whether it is facilitatory or inhibitory depends on factors such as exposure duration, prime–target relative frequency, the lexical status of the prime, and neighborhood density. For example, in short exposure durations, the prime is not consciously perceived. If the primes and targets have overlapping orthographic structures, any processing carried out on the prime could be used to locate the target, shortening its recognition. In contrast, with longer exposure duration, the prime may be recognized, and since orthographically similar word forms may compete with one another as part of the recognition process, the prime may suppress the processing of the target. In line with this argument, Chateau and Jared (2000) indeed reported strong effects of orthographic facilitation with a prime exposure of 30 ms but strong inhibition with a prime exposure of 60 ms. Regarding frequency, in general, stronger facilitation or inhibition is expected when the frequency of the prime exceeds that of the target (e.g., Segui & Grainger, 1990). As to the lexical status of the prime, nonword primes that are orthographically similar to the targets produce stronger priming, since no prime–target competition is expected for nonword primes (e.g., Holyk & Pexman, 2004). Finally, form-priming facilitation also depends on neighborhood density: Strong facilitation is obtained for word targets having few orthographic neighbors and weak facilitation for words having many (e.g., Forster & Taft, 1994). This is because the prime predicts the target with greater efficiency when the orthographic neighborhood includes but a few candidates than when it includes many.

Masked form priming (positive or negative) is a robust effect in visual word recognition and has been repeatedly demonstrated in numerous studies across many Indo-European languages, such as English (e.g., Davis & Lupker, 2006), French (Ferrand & Grainger, 1992), Dutch (Van Heuven, Dijkstra, Grainger, & Schriefers, 2001), and Spanish (e.g. Perea & Rosa, 2000). In accordance with the aforementioned various experimental factors, most masked priming studies reported either significant facilitation or significant inhibition when primes and targets shared orthographic form.[1] Taken together, these studies are compatible with the suggestion that orthographic constraints determine the structure of lexical space in Indo-European languages.

What about Hebrew then? In a recent study, Frost et al. (2005) have shown a very different pattern of results in this language. In a set of eight experiments, they reported that no form-orthographic priming could be obtained in Hebrew or in Arabic, also a Semitic language. Thus, orthographically similar prime–target pairs differing by one letter only did not show any significant facilitation or inhibition in any experimental condition. Moreover, in sharp contrast to Indo-European languages, masked form priming seemed unaffected by the lexical status of the prime or by neighborhood density. Of special interest in the present context were two experiments involving bilingual subjects. In these two experiments, Hebrew–English (Experiment 3a) and English–Hebrew (Experiment 3b) bilinguals were presented with form-related primes and targets in Hebrew and in English. When tested in English, these bilingual speakers indeed demonstrated robust form priming. However, in both experiments, no such effect was obtained when these same subjects were tested with Hebrew material.

The interpretation of these findings was that the Hebrew lexical space is organized in a radically different manner than that of English and other Indo-European languages. In the latter case, the orthographic dimensions of the space specify words in terms of the constituent letters and their absolute and relative positions. In contrast, the Hebrew lexical space may be structured according to the morphological roots. This would mean that all words that contain the same root would be clustered together, and the perceptual distance between two words containing different roots would be uncorrelated with their overall orthographic similarity. This conclusion is further supported when considering masked morphological priming.

EFFECT OF PRIME–TARGET MORPHOLOGICAL OVERLAP

In contrast to the form orthographic priming effects that were consistently found to be small and unreliable in Hebrew, robust masked morphological priming effects have been repeatedly reported in a series of studies. The main finding concerns the role of the root morpheme in visual word recognition. Root primes presented in isolation or contained in verbal or nominal derivations were found to facilitate both lexical decision and the naming of target words that were derived from these roots (e.g., Deutsch, Frost & Forster, 1998; Frost et al., 1997, 2005; Frost et al., 2000). In other words, masked morphological priming is always obtained when the prime consists of the root letters or a derivation of that root, and the target consists of the root letters or a derivation of the root. Finally, the morphological priming effect seems unaffected by semantic transparency or lack thereof. These findings strongly suggest that Hebrew readers extract the root morpheme during word recognition and that these morphemic units govern lexical access.

AU: "lexical decision making"?

Au: Frost, Deutsch, & Forster or Frost, Deutsch, Gilboa, et al.?

The results from Indo-European languages are more difficult to assess. At first glance, masked morphological priming is also consistently found in Indo-European languages. Significant priming effects were reported in English (e.g., Rastle & Davis, 2003), in Dutch (e.g., Diependaele, Sandra, & Grainger, 2005), in French (e.g., Longtin, Segui, & Halle, 2003), and in Spanish (Badecker & Allen, 2002). The crucial question is, however, whether these effects are comparable to those obtained in Hebrew. One striking feature of masked morphological priming studies in Indo-European languages is an asymmetry in the position of primes and targets. It seems that robust morphological priming is obtained when the prime is a derivation and the target is a stem (*darkness–dark*), but less so when this order is reversed. A recent review of masked morphological priming effects (Brysbaert & Rastle, XXXX) reveals that out of two dozen reported studies, more than 20 followed the derivation-stem procedure. Although a few studies (e.g., Feldman & Soltano, 1999) have reported significant morphological priming when the prime was the stem rather than the derivation (*dark–darkness*) or when both primes and targets were derivations (*darkly–darkness*), in general it is safe to say that such priming effects are not as robust. In Hebrew, on the other hand, the position of the prime and target is of no consequence. Identical effects are obtained whether the prime is a root or a derivation.

Au; Add year. See comment in refs.

The second issue concerns the impact of semantic transparency on morphological priming. In Hebrew, semantic transparency does not modulate priming. Thus, two root derivations such as *targil–meragel* (both derived from the root *RGL*, which conveys the meaning of foot action, the former meaning "exercise," the latter meaning "spy") produce priming effects similar in magnitude to two derivations that are semantically related. The results from English are mixed. Although most studies suggested that masked morphological priming is not modulated by semantic transparency (e.g., Rastle, Davis, & New, 2004) some studies found an opposite trend (e.g., Diependaele et al., 2005; also see Rastle & Davis, in press, for a review). One striking feature of masked morphological priming in English is the facilitation obtained by prime–target pairs such as *brother–BROTH*, which are pseudoderived. It is this finding that is taken as evidence that masked morphological priming effects in English are independent of semantic transparency (e.g., Rastle et al., 2004), in sharp contrast to the Hebrew studies that examined true morphological derivations rather than pseudoderivations. However, it is possible that *brother–BROTH* priming simply reflects a morpho-orthographic automatic parsing procedure characteristic of languages based on the concatenation of highly frequent prefix or suffix bigrams such as *ER* (see Diependaele et al., 2005, and Rastle & Davis, in press, for a discussion).

Are masked morphological priming effects in Hebrew and English different? Since it is difficult to compare different studies in different languages, the most compelling evidence for cross-linguistic differences should come from experiments that employ identical experimental manipulations on bilingual subjects. Such a study was recently conducted in our laboratory. In this experiment Hebrew–English bilingual subjects were presented with an identical morphological priming manipulation in Hebrew and in English. The stimuli in the experiment were 48 prime–target pairs in Hebrew and 48 in English. All pairs were comprised of root or stem primes and derivation targets. For example, the prime *fail* was paired with the target *failure* in the related condition, and *failure* was primed by *lure* in the control condition, a word–prime contained in the target yet not the stem. The priming effect was, thus, determined by the facilitation caused by *fail* relative to that of *lure* for the target *failure*. The stimuli in Hebrew were constructed in the same way. In fact, many of the Hebrew prime–target pairs consisted of actual translations of the English stimuli. For instance, the prime root *KŠL* (meaning "to fail") was followed by the target *kišalon* ("a failure"). In the control condition, the letters of the prime *ŠLO* (meaning "his") were again contained in the target but were not the root morpheme. As in English, the priming effect was determined by the facilitation caused by *KŠL* relative to *ŠLO* for the target *kišalon*. The experiment consisted of two blocks: one with the English stimuli and one with the Hebrew stimuli. Thirty-six Hebrew–English balanced bilinguals participated in the study. The procedure and apparatus were identical to the masked priming experiments reported by Frost et al. (2005) with form priming.

The left side of Table 12.1 presents the morphological priming effects obtained in Hebrew and in English, and the right side of the table summarizes the combined orthographic priming effects reported in Experiments 3a and 3b by Frost et al. (2005), both with bilingual subjects. The pattern of results seems straightforward,

TABLE 12.1

The Double Dissociation: Masked Morphological and Masked Orthographic Priming Effects in Hebrew and in English

	Morphological Priming			Orthographic Priming		
Condition	**Related**	**Unrelated**	**Priming Effect**	**Related**	**Unrelated**	**Priming Effect**
Hebrew	540	557	17**	570	578	8 (*ns*)
English	563	573	10 (*ns*)	605	635	30**

Note: Results reported by Frost et al. (2005) and Frost (2007). Subjects are balanced bilinguals. AU: Check year for Frost.

AU: Explanation for asterisks correct? $^{**}p < .01$.

demonstrating a double dissociation. Whereas in Hebrew orthographic priming effects were small and unreliable, in English they were significant and robust. In contrast, morphological priming effects in Hebrew were significant and robust, whereas in English they were small and unreliable.

Taken together, these results suggest again that word organization in lexical space of Semitic languages and Indo-European languages is defined by different principles. In Hebrew, words are organized by root morphemes. Therefore, root priming produces significant facilitation, whereas orthographic priming does not. Conversely, words in English are aligned in lexical space by orthographic similarity. As a result, form priming is robust and masked morphological priming appears to be more fragile.

PROCESSING MORPHOLOGICAL INFORMATION IN THE PARAFOVEA

The evidence reported so far for early morphological decomposition is based on priming under masked presentations. The masked-priming paradigm is particularly useful for exploring early processes of word recognition because the brief presentation of the prime combined with forward and backward masking prevents the full conscious identification of the prime. Consequently, the priming effect obtained in this procedure is not influenced by the participants' appreciation of the prime–target morphological or orthographic relation, as is the case with some long-term priming effects.

Recently, converging evidence for morphological decomposition was obtained in Hebrew by measuring preview benefit effects induced by presenting morphological information in the parafovea. This procedure measures how the information extracted from a word before the eyes land on it affects the identification of that word. This information is considered parafoveal because it is typically about 5 to 10 characters from fixation and, thus, is near, but not in, the foveal region. A large body of research on eye movements in reading (see Rayner, 1998, for a review) has revealed that although the perceptual span from which readers extract information is small, it is not restricted to the fixated word, and readers can extract information from the next word or two as well. The common finding (in languages written from left to right) is that reading is significantly slowed if the parafoveal information about the word to the right of the fixated word is withheld. A detailed assessment of the benefit from a parafoveal preview can be provided using the boundary technique (Rayner, 1975). This technique involves rapidly changing a single word during the saccade in which the eyes move to fixate the word. The display change is triggered when the eyes cross an invisible boundary just prior to the target word. When preview benefit is assessed during sentence reading, the fixation time on the target word is the primary dependent measure. Thus, participants are not required to perform any external task aside from naturally reading the text.

An important feature of the boundary technique is that readers are virtually unaware of the display change and are also unable to identify the stimulus in the parafovea. Nevertheless, the parafoveal information is apparently integrated with the subsequent activation of the foveal word, as parafoveal information was found to facilitate the identification of the foveal target word (Rayner, McConkie, & Zola, 1980). Using the boundary technique, it has been shown that both orthographic (Inhoff, 1989; Rayner, Well, Pollatsek, & Bertera, 1982) and phonological information (Henderson, Dixon, Peterson, Twilley, & Ferreira, 1995; Pollatsek, Lesch, Morris, & Rayner, 1992) are extracted from the parafovea. The explanation for parafoveal benefit resembles the one for masked priming effects: Information extracted from the parafovea leads to partial activation of the lexicon, and this activation is integrated with the later activation caused by the processing of the foveal word (Rayner, 1998; see Forster & Davis, 1984, for masked priming).

Interestingly, only a few studies have manipulated morphological factors in the parafovea while measuring preview effects in English (Inhoff, 1989; Kambe, 2004; Lima, 1987; Rayner, Juhasz, White, & Liversedge, 2007). These studies used previews that shared a morpheme with the target word. The overall pattern of results obtained from studies in English is consistent: No greater benefit from morphologically related previews was found relative to control previews that shared as many letters with the target (in the same positions) as the morphemic previews. These findings do not converge with morphological priming effects found in English under masked presentation, as previously described.

What about Hebrew? Using a manipulation similar to the English studies, Deutsch, Frost, Pollatsek, and Rayner (2000) examined parafoveal preview benefit effects in Hebrew, focusing on morphological relatedness between previews and targets. The results showed that lexical decisions for root derivation targets were facilitated when the root letters were presented in the parafovea, relative to a control condition in which three other letters were presented parafoveally. Figure 12.1 illustrates an example of the preview manipulation in Hebrew. The parafoveal stimulus is the root ברש BRŠ ("to brush"). While the eye crosses the invisible boundary, the parafoveal stimulus is replaced by the target word מברשת MBRŠT ("a brush").

In a subsequent study, Deutsch, Frost, Peleg, Pollatsek, and Rayner (2003) examined sentence processing rather than single word identification. The measure

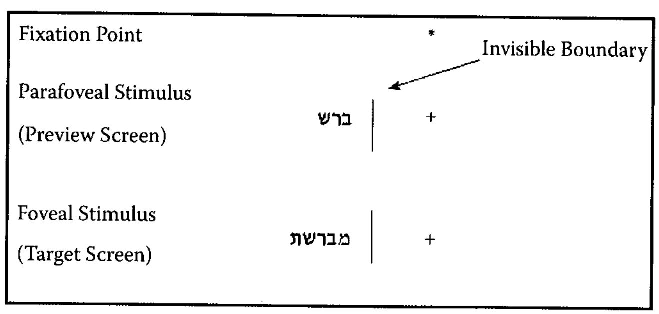

FIGURE 12.1 The parafoveal preview benefit paradigm. Example of the stimuli employed by Deutsch et al. (2000).

TABLE 12.2
Parafoveal Preview Benefit Effects with Morphologically Related Preview

	Morphological Preview	Orthographic Control
Deutsch et al. (2000), Lexical decision latencies	566 15 ms**	581
Deutsch et al. (2003), First fixation in milliseconds	226 12 ms**	238
Deutsch et al. (2003), Gaze duration in milliseconds	267 12 ms**	279

Note: Results reported by Deutsch et al. (2000) monitoring lexical decisions, and by Deutsch et al. (2003) monitoring first fixation and gaze duration during sentence reading.

AU: Explanation for asterisks correct?

**$p < .01$.

employed in this study was *gaze duration*, the sum of the durations of all fixations made on a target word from the first time the reader's eyes land on the word until the eyes move to preceding or following parts of the sentence. Deutsch and her colleagues demonstrated that a preview of a word derived from the same root morpheme as the foveal target word shortened processing of the target word, compared to a preview that was as orthographically similar to the target as the morphemic preview.

Taken together, these studies stand in sharp contrast to results obtained in English. The results suggest that morphological information is extracted from the parafovea in the initial phases of word recognition in Hebrew. The target of this search is the root (although some facilitation was recently demonstrated for verbal word patterns as well; Deutsch, Frost, Pollatsek, & Rayner, 2005). In other words, whereas English readers seem to simply register the orthographic structure of words in the parafovea, Hebrew readers seem to engage in extensive morphological processing, including searching for the root information. The findings using parafoveal presentation, therefore, provide additional support for the structural-ecological view.

THE IMPACT OF LETTER TRANSPOSITION

In recent years, several studies have consistently reported robust form-orthographic priming effects when primes and targets shared the identity of individual letters but in a different order (e.g., *gadren* priming *garden*; Perea & Lupker, 2003; Schoonbaert & Grainger, 2004; for a discussion, Grainger & Van Heuven, 2003). Masked priming with transposed letters was reported in several Indo-European languages including English (e.g., Lupker & Perea, 2003), French (Schoonbaert & Grainger, 2004), and Spanish (Perea & Lupker, 2004). 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 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 & Rumelhart, 1981, or the dual-route cascaded [DRC] model by Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001). Consequently, a new generation of computational models that focus on context-sensitive coding of relative letter position has emerged (e.g., Grainger & Van Heuven, 2003; Grainger & Whitney, 2004; Whitney, 2001; see Schoonbaert & Grainger, 2004, for a discussion). For example, to account for the letter transposition effect, Grainger and Whitney have offered a new approach to letter position coding that is based on "open bigram" units (Grainger & Whitney, 2004; Whitney, 2001). Open bigrams do not contain precise information about which letter is adjacent to which (i.e., contiguity), meaning the word *FORM*, for example, would be represented by activation of the bigram units *FO*, *FR*, *OR*, *OM*, and *RM*. A transposition prime, such as *from*, would then share all but one of these units, namely *FR, FO, RM* and *OM*.

Perhaps the most dramatic demonstration of how reading is resilient to letter transposition in Indo-European languages is a paragraph that has been circulating via the Internet, especially in the reading research community. The paragraph alluded to some fictitious research conducted at Cambridge University effectively demonstrating a puzzling phenomenon: the text could be read without much difficulty despite the fact that almost every word included letter-transpositions: "Aoccdrnig to rscheearch at Cmabrigde Uinervtisy, it deosn't mttaer in waht oredr the ltteers in a wrod are, the olny iprmoetnt tihng is taht the frist and lsat ltteer be at the rghit pclae ...." The phenomenon has been labeled the "Cambridge University effect," and since its first appearance in 2003, it has become somewhat of an urban legend. The English text has since been translated into French, Spanish, Italian, Dutch, German, Danish, Finnish, Icelandic, Portuguese, Swedish, Russian, Hungarian, Irish, Polish, and Albanian. A recent study monitoring eye movements showed that although some transpositions pose some difficulty, others are pretty easy to read (Rayner, White, Johnson, & Liversedge, 2006).

How would letter transpositions affect reading in Hebrew? The structural-ecological view has clear predictions: If lexical access in Hebrew is indeed based on a preliminary search of a triliteral 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 3,000 triconsonantal 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 Š.L.X ("to send") can be altered to produce the root X.L.Š ("to dominate"), X.Š.L ("to toughen"), and L.X.Š ("to whisper"). In fact, one can hardly find a triconsonantal root that does not share its set of three letters with other roots. If lexical access in Hebrew requires the identification of a specific root, then 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.Š, for example, need to be differentiated from those of Š.L.X, L.X.Š, and X.Š.L. If this hypothesis is correct, the Cambridge University effect will not work in a Semitic language such as Hebrew. The 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 and Frost (2007) investigated this intriguing possibility by examining reading performance of Hebrew–English bilinguals, using rapid serial visual presentation (RSVP; see Potter, 1984). In this study, 28 Hebrew–English balanced bilinguals were presented with 20 sentences in English and 20 in Hebrew, 10 of which had transposed-letter words and 10 of which were intact. The sentences were presented on the screen word by word, and each word appeared for 200 ms. Following the final word, subjects had to vocally produce the entire sentence. The aim of the experiment was to measure the relative level of performance in Hebrew and in English on sentences that involved the transposition of letters and to compare these with the presentation of the intact sentences. Velan and Frost also examined whether the subjects were at all aware of the transposition manipulation in each language, given the rapid presentation of words on the screen.

The results of Velan et al. (2007) are presented in Figure 12.2. The figure demonstrates 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, Velan and Frost found that subjects were virtually unaware of the transposition manipulation. For about one third of their subjects, detection of transpositions in English materials was at chance level. Measuring the sensitivity of subjects to the transposition manipulation, *d′*, detecting transpositions for English material was found to be relatively low, about 0.86. This finding seems to converge with recent results reporting strong masked-priming effects with transposed letters. The striking feature of Figure 12.2, however, is the contrast with Hebrew. The correct report of Hebrew words dropped

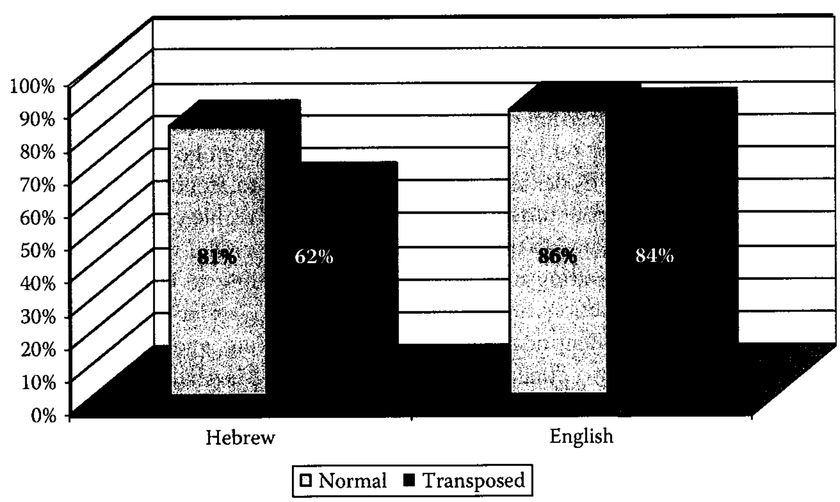

FIGURE 12.2 Effects of letter transposition in Hebrew and in English using rapid serial visual presentation. Data from Velan and Frost (2007).

dramatically in sentences containing transpositions, from 81% correct to 62% correct. Also, for the Hebrew material, detection of transposition was immediate, and d' values were exceedingly high, about 2.51. Since the participants in the present 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 the speakers of the two languages. Moreover, as performance in English and in Hebrew was very similar with normal sentences, the poor performance with transposed stimuli cannot be attributed to content complexity; rather, this reflects a genuine difference in sensitivity to transposition in the two languages.

What then is the source of the dramatic cross-linguistic differences in the impact of letter transposition on reading? Similar to the previous experimental manipulations, the effects of letter transposition probably reflect the principles of how lexical space is defined and organized and do not emerge from the peripheral registering of letters in alphabetic orthographies. If lexical access in a language such as Hebrew indeed requires the correct identification of a specific root morpheme and many roots share the same set of letters, the primary task of the lexical system is to determine the exact identity and order of letters constituting the root morpheme. Root-letter transpositions will, therefore, prevent the processing system from extracting the correct root identity necessary for the lexical search. This would produce genuine differences in sensitivity to letter transpositions in Hebrew, when compared with English. Thus, whereas readers of English seem to display some "blindness" to transpositions in RSVP, readers of Hebrew seem to display extreme difficulties in reading transposed text. Thus, the dramatic difference in the impact of letter transposition in English and in Hebrew provides additional support for the structural-ecological view.

EVIDENCE FROM READING DISORDERS

The final argument in support of the structural-ecological view concerns converging evidence from reading disorders in Hebrew. The question is whether the morphological constraint on lexical structure in Hebrew can be demonstrated in some specific forms of dyslexia that are characteristic to Hebrew readers only. Bearing in mind the impact of letter transposition, the possible relevant disorders to consider are those related to the visual processing of printed words, especially those related to the encoding of letter position. According to Ellis and Young (1988), three distinct functions are relevant to peripheral disorders related to visual analysis of print: letter identification, letter-to-word binding, and encoding of letter position. The first two concern letter agnosia (e.g., Marshall & Newcombe, 1973) and letter migration problems (e.g., Shallice & Warrington, 1977), which are characteristic of any alphabetic orthography. The third dysfunction, however, may have immediate relevance to reading Hebrew. The question is whether it is possible to demonstrate a *selective* impairment related only to the positions of letters, and, if so, whether readers of Hebrew would be more affected by it than readers of English.

The answer to both questions seems to be positive. Friedmann and Gvion (2001, 2005) have reported two cases of Hebrew-speaking acquired dyslexic patients with left parieto-occipital damage (BS, 75 years old, with ischemic infarct; and PY, 70 years old, with a lesion following tumor removal), who both had intact letter identification and intact binding of letters to words but a deficit in the positioning of letters within a word. The deficit was hence labeled *letter position dyslexia* (LPD). Interestingly, as Friedmann and her colleagues suggested, pure cases of LPD were never reported in Indo-European languages. Recently, Friedmann and Rahamim (in press) reported 11 cases of developmental LPD, again, a selective deficit of letter position within words, without letter identity errors or word migration errors and without phonemic awareness deficit or output deficit. All of these cases involve Hebrew speakers. Why then is LPD more prevalent in Hebrew? Considering, the characteristics of LPD, the answer seems straightforward. First, errors in LPD occur almost exclusively in the middle letters so that initial and final letters remain in their original position. Second, the LPD patients reported by Friedmann and her colleagues tended to naturally search for a lexical candidate and to produce words. Consequently, errors occurred mainly in "migratable" words, when transpositions produce another lexical candidate—another word. What is then the main difference between Hebrew and English? First, because in Hebrew most vowels are not represented in print, on average, words are shorter than in English and each word has many orthographic neighbors. Second, because of the combinatorial aspect of root letters, letter transpositions would in all probability result in an existing word. Thus, in English, patients who suffer from a dysfunction related to letter position encoding perform quite well, like normal readers would perform when reading a text with jumbled letters. Most texts would appear to them as the text implicated in the Cambridge University effect. As we found with normal subjects, reading of transposed letters in English does not significantly hinder performance. In contrast, in Hebrew, letter transpositions have dramatic impact on reading. Patients who suffer from LPD would then show a marked deficit. Since migratable words are the rule in Hebrew, LPD is instantly detected. Patients do not simply "recover" from transposition and "fix" the correct letter order; rather, they produce another word derived from a root that has the same letter cluster but with a different sequence. In English, migratable words such as *clam–calm* are the exception, not the rule. Thus, it is more difficult to diagnose LPD in English, and the dysfunction related to letter order is often covert.

Au: Add Friedmann & Rahamim to refs.

SUMMARY AND CONCLUSIONS

The present discussion raises a fundamental question in visual word recognition: Could there be a qualitative difference in the principles of lexical organization and visual word recognition processes in different alphabetic orthographies? The empirical evidence reviewed here covers a variety of experimental paradigms that were employed in English, an Indo-European language, and in Hebrew, a Semitic language. First, when masked orthographic and masked morphological priming effects are compared, a double dissociation emerges, and Hebrew and English seem to present opposite results: unconstrained morphological priming and weak orthographic priming effects in Hebrew versus constrained morphological priming and robust orthographic priming in English. Second, converging evidence is provided by comparing parafoveal preview benefits in these two languages. Strong morphological preview effects are consistently obtained in Hebrew, yet these are not found in English. Third, a marked difference in the effects of letter transposition is found in these two languages. Whereas reading in English seems almost unaffected by jumbled letters, reading in Hebrew is seriously hindered. Finally, reading disorders, such as letter-position dyslexia, are prevalent in Hebrew but not in English.

Taken together, these findings seem to reveal a qualitative difference between Hebrew and English, suggesting that their respective lexical spaces are defined according to different principles: In English, lexical space is defined according to linear alphabetic constraints, whereas in Hebrew it is defined according to root morphemes. How to implement these cross-linguistic differences in current models of visual word recognition necessarily depends on the type of model chosen. For example, in attractor-based models (Rueckl, 2002), the position of attractors in lexical space would be determined by all of the letters in Indo-European languages, but only by the root letters in Hebrew. In practical terms, this would mean that for English, words are aligned in lexical space taking their full sequence of letters into account, whereas for Hebrew, all words derived from a given root would presumably be clustered together. An active search model, such as the entry-opening model (Forster, 1999; Forster & Davis, 1984), would need to propose that in English, allocation of words into bins is based on orthographic neighborhoods, whereas in Hebrew, the grouping of entries into bins would be based on the root letters only. Hence, all words that contain the same root letters would be located in the same bin. But note that whatever type of model is chosen, it seems evident that the processing of print would necessarily reflect the structural differences between Hebrew and English. Findings from beginner and skilled readers indeed show interplay between a computational process that involves letter-by-letter units, along with a parallel computational process that involves the search for morphemic units (see Frost, 2006, for a discussion). Subsequently, the comparison of English and Hebrew demonstrates that linguistic considerations should be the main source of constraints on any theory of lexical organization. This is the essence of the structural-ecological view.

NOTE

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