Many ways to read your vowels—Neural processing of diacritics and vowel letters in Hebrew

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ABSTRACT

The current study examined the effect of orthographic transparency and familiarity on brain mechanisms involved in word recognition in adult Hebrew readers. We compared the effects of diacritics that provide transparent but less familiar information and vowel letters that increase orthographic transparency without compromising familiarity. Brain activation was measured in 18 adults during oral reading of single words, while manipulating the presence of diacritic marks, the presence of a vowel letter, and word length (3 vs. 4 consonants). We found opposite effects of diacritics and vowel letters on temporo-parietal regions associated with mapping orthography to phonology. The increase in activation for diacritic marks and the decrease in activation for vowel letters in these regions suggest that the greater familiarity of vowel letters compared to diacritics overrides the effect of orthographic transparency. Vowel letters also reduced activation in regions associated with semantic processing in unpointed words, and were thus distinct from the effect of an additional consonant. Altogether the results suggest that both orthographic transparency and familiarity contribute to word recognition.

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Introduction

Writing systems represent units of spoken language, and thus are structured so that they optimally represent the languages' phonological spaces, and their mapping into semantic meanings (Frost, 2012). It is customary to characterize writing systems according to their orthographic transparency. In transparent orthographies, such as German or Spanish, the grapheme to phoneme correspondence is consistent, while in opaque orthographies, such as English or French, the grapheme to phoneme correspondence is less consistent.

The effects of orthographic transparency and the role of phonology in word recognition

There is a debate in the literature regarding whether phonological information mediates access to the mental visual word lexicon for adult readers. The Orthographic Depth Hypothesis (Katz and Frost, 1992), inspired by the Dual Route Model (Coltheart et al., 2001), suggests that readers rely on one of two routes for reading, depending on the demands of the specific orthography. In more transparent orthographies readers access to words' meaning through its phonology, by assembled (letter by letter) reading. In opaque orthographies, access through phonology is not obligatory and meaning can be accessed directly by decoding of large orthographic units (whole-word) (Katz and Frost, 1992).

In contrast, according to connectionist models (McClelland and Rumelhart, 1981; Seidenberg and McClelland, 1989) access to phonology is obligatory for reading in all orthographies, and there are more than just two possible routes for reading. In addition, the size of the units in the orthography-to-phonology mappings is determined by orthographic transparency, but also by reading proficiency and language characteristics, such as phonological and morphological structure (Frost, 2005; Perfetti, 2003; Perfetti et al., 2005; Ziegler and Goswami, 2005).

Beyond transparency and phonology

A comprehensive review by Share (2008b), suggests that an important aspect of reading, neglected by the theories formerly described is the familiarity of the word being read. The Lexical Quality Hypothesis (Perfetti, 2007) addressed this concern, and emphasizes the reader's experience. According to this hypothesis the quality and stability of lexical representations of written words determine the accuracy and fluency of word recognition and comprehension. Lexical quality is determined both by attributes of the reader (the individual's reading experience and their familiarity with the word) and by attributes of

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the specific word (its phonology, orthography, frequency, etc.). Hence, in addition to the orthographic transparency of the writing system, word recognition is affected by multiple factors that vary across different orthographies, words and readers. Thus, for skilled readers, frequent word forms have good lexical quality that contributes to effective and stable retrieval of the word's identity (Perfetti, 2007).

Neural correlates of reading a transparent orthography

Inspired by the idea that orthographic transparency may affect the specific mechanisms involved in reading in different languages, a growing body of research addressed the effect of consistency between orthography and phonology by comparing between readers of transparent and opaque orthographies in different languages. For example, Paulesu et al. (2000) have found different brain activation in a PET study comparing oral word reading in English (opaque orthography) and Italian (transparent orthography) readers. English readers showed stronger activation in the left posterior inferior temporal gyrus and the anterior IFG suggested to be associated with a whole word lexical retrieval strategy, while Italians showed stronger activation in left superior temporal regions, associated with phonological processing. More recently a meta-analysis of reading studies in western and eastern orthographies showed that activation in the left temporo-parietal junction (TPJ; BA 39/40) was specific for alphabetic but not for non-alphabetic orthographies (Bolger et al., 2005). The effect of orthographic transparency was also found in the dorsal part of left IFG following training in an artificial script. This region showed greater activation for reading the alphabetic compared to the non-alphabetic script (Bitan et al., 2005).

Neuroimaging studies with bilinguals provide an opportunity to examine the effect of orthographic transparency within-subjects, but these effects often interact with language proficiency. For example, activation in the left inferior parietal lobule (IPL; BA 40) was related to reading Hindi which is more transparent than English when proficiency in both languages was balanced, and to reading in both orthographies when proficiency was greater in Hindi (Das et al., 2011). In contrast, in a study with Spanish-English bilinguals, activation in left IPL was related to reading English, although it was less transparent and more proficient than Spanish (Meschyan and Hernandez, 2006).

Orthographic familiarity effects on brain activation in word recognition are usually examined by comparing high to low frequency words, and between real and pseudowords. Neuroimaging studies in English, German and Japanese found that higher words' familiarity, frequency and imageability decreased activation in left IFG (Heim et al., 2012; Ischebeck et al., 2004; Pugh et al., 2008) and superior temporal gyrus (STG) for skilled readers (Pugh et al., 2008). These findings are consistent with reduced efforts in lexical and phonological access in familiar words.

Transparency and familiarity in the Hebrew orthography

Phonemes in Hebrew are represented with three graphemic systems: 18 letters that represent only consonants, four vowel letters (the אהוי (AHWY) letter set) that represent both vowels and consonants, and diacritic marks that represent vowels (Ravid, 2005). The inclusion of diacritic marks is optional, resulting in one script with two versions that differ in their orthographic transparency: an opaque writing system (unpointed—without diacritic marks) and a shallow writing system (pointed—with diacritic marks) (Bar-On, 2010; Share, 2008a). The unpointed opaque version includes mostly consonants graphemes, while vowel sounds are only partially represented by vowel letters. Moreover, some vowel letters are ambiguous because they represent more than one vowel, and a consonant. This creates an extensive phonological under-specification as well as pervasive homography (Bar-On, 2010). In contrast, the pointed, transparent version contains diacritic marks (in addition to consonants and vowel letters) which provide full representation of vowel sounds.

This duality provides a unique opportunity to examine the effect of orthographic transparency on reading in a within-language within-subject design. However, it should also be noted that pointed words are mostly encountered during early years of reading acquisition, and are absent from most texts for skilled readers. Therefore, in the case of adult Hebrew readers the highly transparent script is also less frequently encountered.

At the beginning stages of reading acquisition children learn to read the pointed script, which allows them to rely on serial bottom-up ortho-phono mapping to identify written words (Bar-On, 2010; Gur, 2005; Schiff et al., 2012; Shany et al., 2011). During the development of reading skills, diacritics become less crucial and are replaced by a greater reliance on higher-order word-level lexical and morphological information, while knowledge and use of diacritics declines over time (Bar-On, 2010).

While diacritics provide full and unambiguous vowel information, vowel letters provide only partial and ambiguous vowel information. All vowel letters denote both consonants and vowels, and some of them represent more than one vowel. For example, the letter ו ('vav') can represent the consonant /v/ the vowel /o/, or the vowel /u/. Vowels at the end of words are almost always represented by vowel letters, while in the middle of a word /a/ and /e/ are never represented by a vowel letter, while /i/ and /o/ are represented by vowel letters in some words. However, in contrast to diacritics which are superimposed under or above the consonants, vowel letters are written in line with the consonants in a written word. Importantly, while the presence of diacritics is optional and may decrease familiarity with the words' orthographic pattern for adult readers, most Hebrew words appear consistently either with or without vowel letters, so vowel letters do not change the word familiarity. Thus, comparing the effects of diacritics and vowel letters enables us to examine different degrees of orthographic transparency, with stronger effects expected for diacritics as they provide more phonological information. However, we hypothesized that while vowel letters do not enhance orthographic transparency to the same degree as diacritics, they do not compromise familiarity either, hence their overall benefit for word recognition may be larger.

A large number of behavioral studies have examined the role of diacritics in word recognition for Hebrew readers at various stages of reading acquisition. Diacritics were found to facilitate word recognition in early stages of reading acquisition (Harel-koren, 2007; Navon and Shimron, 1981; Ravid, 1996; Shany et al., 2011; Shimron and Sivan, 1994). For skilled readers, different studies show mixed results: diacritics either facilitate (Koriat, 1984, 1985; Navon and Shimron, 1981; Shimron and Navon, 1982) or had no effect (Bentin and Frost, 1987; Harel-koren, 2007; Schiff and Ravid, 2004; Shimron and Sivan, 1994) on word recognition. Developmental studies suggest that in very early stages of reading acquisition Hebrew readers rely mostly on diacritics, and that the facilitating effect of vowel letters on word recognition develops over time with increasing exposure to unpointed words (Harel-koren, 2007; Schiff, 2003; Shany et al., 2011).

In our behavioral study (Weiss et al., 2015), skilled Hebrew readers showed an interaction of diacritics and word length in reading latency. In pointed words they demonstrated a classic length effect (longer words were read slower and less accurately than short words), while in unpointed words they demonstrated a reversed length effect (longer words were read faster and more accurately), suggesting reliance on mapping of smaller orthographic units in pointed compared to unpointed words. In contrast to the effect of diacritics, vowel letters, improved accuracy across all conditions, and decreased latency in unpointed words. The effect of vowel letters on reading latency specifically in unpointed words suggests that their facilitative effect is due to increased orthographic transparency.

Neural correlates of reading pointed words in Hebrew and Arabic

The research on the effect of diacritics on brain activity in Semitic languages is scarce. ERP studies that examined the role of diacritics in