THE ROOTS OF CONSONANT BIAS: A PSYCHOLINGUISTIC STUDY OF STEM CONSONANT FACILITATION IN HEBREW*

SI BERREBI
Tel Aviv University

1 Introduction

It is the received view in psycholinguistic literature that consonantal roots (hereafter *roots*) are the key to lexical retrieval in Semitic languages (Frost et al., 1997 and onward). The present study challenges this view, first, by presenting the results of two auditory priming experiments, in which orthography, semantics, and phonology were taken into account in a manner that was not attempted in previous works; second, by a re-examination of previous results in the field. The results of the current experiments are comparable to those of similar experiments in English and French (Delle Luce et al., 2014), suggesting that stem consonants are effective facilitators for lexical retrieval, regardless of the morphological or semantic relations that hold between prime and target. As for the various effects that were attributed to the root morpheme, an alternative account is suggested which puts speakers and readers of Semitic languages on a par with their Indo-European counterparts, the only difference being the distributional properties of their respective orthographic systems. This view yields an immediate empirical prediction: That particular Semitic words which happen to have "Indo-European"-like distributional properties will show similar effects in both language families. This prediction is borne out for both Arabic (Perea et al., 2014) and Hebrew (Velan and Frost, 2011).[1]

* This paper is greatly indebted to Outi Bat-El and Aya Meltzer-Asscher, whose advice, comments, and discussions were invaluable. I also thank the audiences at the Phonological Circle at Tel Aviv University, the TAU colloquium, and the Semitic morphology reading group at the Hebrew University, as well as Orna Peleg, Roey Gafter, Noa Bassel, Almog Simchon, Tal Ness, Hadass Zaidenberg, Ezer Rasin, Avi Mizrachi, Inbal Abarbanel, and Noa Brandel. All the usual disclaimers apply. The study was partially funded by The Humanities Fund.

[1] Velan and Frost (2011) report this finding only for a particular set of words. In any case, their model does not explain orthographic similarity effects, as discussed in §3.

The traditional Root Approach has theoretical origins, as well as theoretical opponents. Bat-El (1994) shows that a whole-word phonological approach is necessary to predict at least some word formation processes in Hebrew. Further, such an approach would utilize the same inventory of formal tools in creating both Semitic and non-Semitic phonological rules/constraints. The current paper poses a Universalist challenge to the alleged psychological reality of the root.

2 What Is Listed in the Mental Lexicon?

2.1 Two Approaches to the Morphology of Semitic Words

There is a longstanding debate about the morphological structure of Semitic words, with two main approaches in the literature: The Root Approach and the Universalist Approach.

The Root Approach, which involves root-to-template mapping, suggests that the lexicon of a Semitic language consists of a list of root morphemes. Root morphemes are ordered triplets (and, more rarely, pairs or quadruples) of consonants. In addition to them, the lexicon includes a list of configurations (called *Binyanim* for verbs and *Mishkalim* for nouns), which are combined with roots to form words. Within a conservative Root Approach (Moscati, 1980, among many others), the root is a morphological unit "associated with a basic meaning range common to all members of the root: e.g., *k.t.b.* 'to write', *q.b.r.* 'to burry', *q.r.b.* 'to approach', etc. These roots (root morphemes) constitute a fundamental category of lexical morphemes" (Moscati, 1980:71).

The psycholinguistic version of the Root Approach (e.g., Frost et al., 2005; Velan and Frost, 2009, 2011) is more permissive, defining the root only in terms of formal similarity between words that share it; namely, two to four consonants and graphemes in common. That is, morphologically related words are not necessarily semantically related, although the establishment of the root as a meaningful formal unit is assumed to be the result of the semantic relations between most words sharing a root.

In a root approach, words are derived by the composition of two non-concatenative morphemes. For example, the verb *gadal* 'to grow' is derived from the consonantal root *g.d.l.* 'grow' and the configuration *CaCaC*. *gidel* 'to raise', another verb with the same root, is derived in a similar manner: The root *g.d.l.* is mapped into *CiCeC*.

A less conservative view within the Root Approach (Prunet et al., 2000; Arad, 2006), which admits the word-to-word relation in denominative verbs (Bat-El, 1994), allows an additional list of words within the lexicon, which can serve as the base for other words. However, under this approach as well, "the stored lexical units contain roots on a distinct morphemic tier" (Prunet et al., 2000:642). In contrast, In McCarthy's (1979) seminal paper on non-concatenative morphology, all words/stems are represented in the lexicon, in a multi-tiered representation that gives the consonantal root an independent status of a morphological unit.

To conclude, under a conservative Root Approach, words are not listed in the lexicon. Most words are created online, via the composition of a root and a configuration (Moscati, 1980) or a syntactic head (Arad, 2006). Under relaxed versions of the Root Approach, some (Arad) or all (McCarthy) words are listed in the lexicon, while maintaining the root representation at a distinct morphological level. In the psycholinguistic take, roots are considered morphological formatives that are, to a certain extent, free of semantics. Despite differences, under all Root Approaches, the status of the root as a morpheme is preserved.

Conversely, the Universalist Approach (Bat-El, 1994, 2003 et seq.; Ussishkin, 1999, 2000), which employs stem modification, argues in favor of a word/stem-based morphological representation. In the spirit of lexicalism (see Aronoff, 1976; Anderson, 1992), words are listed in the lexicon, and their representations implicitly include the nature of the relations between them. A word or a stem is the base for the derivation, and a process changes the meaning and form of the input word/stem to create another word in a systematic manner. Morphological processes in Semitic languages, as reflected in many paradigms, usually impose a prosodic structure, vocalic template, and/or affixes. There are productive processes as well as less productive ones, but either way, words are derived from other words/stems. For example, *gadal* 'to grow' is a morphologically basic word, while *gidel* 'to raise' is derived directly from *gadal* by assigning a configuration to *gadal*, i.e., *gadal* + σ^{i} σ^{e} + no affix = *gidel*. The vowels of a configuration are pre-specified; they override the vowels of the base word. Here, vowels are written in superscript on the syllable.

The contribution of a particular configuration to a word's meaning depends on the other words sharing the same stem within a paradigm; all morphological theories, to my knowledge, would agree with that. However, the relation between morphologically related words under a root approach is indirect: Words that share stem consonants overlap in one of their morphological units, the root. Under the Universalist Approach, the relation is direct: Stems/words are derived via a mapping of a rule/constraint system into a configuration, to yield a systematic relationship between the two forms.[2]

Importantly, as Bat-El (1994) argues, the consonants of the stem do not form a morphological unit. This is precisely where the Universalist Approach deviates from the word-based approach of McCarthy (1979): Only the former, but not the latter, holds that stem consonants are merely phonological elements; they do not form a unit of any sort. As phonological entities which differ from vowels (a point I will explore in depth below), they might well belong to a different tier, but this tier is predicted to have the characteristics of a phonological tier, comparable to phonological tiers in other languages. Below, I will explore how the characteristics of a functional phonological unit can be distinguished from those of a morphological unit.

The procedures and representations that make up the Semitic lexicon under the Universalist Approach have been proposed in analyses of non-Semitic languages. For example, the alternation between *sing-sang*, *ring-rang* is treated as a vowel change process in Anderson (1992). While vowel change is a common phonological process that usually bears syntactic consequences (Nespor et al., 2003), an analysis that involves the insertion of consonants into pre-configured slots was until recently uniquely proposed for Semitic languages. Table 1 summarizes the derivation of morphologically complex words according to the two frameworks.

[2] In principle, a relationship between words within the Universalist Approach can also be indirect, in that a word C is derived from word B, which was derived from word A. Of course, it is also possible that several words be derived from the same stem/word. For example, *ʃoreʃ* 'root' is the source for both *ʃireʃ* 'rooted out' and *hiʃriʃ* 'ingrained'; all three must be listed in the lexicon.

	UNIVERSALIST APPROACH	ROOT APPROACH
INPUT	a word: *gadal*	a root: *g.d.l.*
DERIVATION	change the vowels	insert root into C slots
OUTPUT	*gidel*	*gidel*
MORPHOLOGICAL UNITS	word, configuration	root, configuration[3]

Table 1. The derivation of *gidel* 'grew.TRANS'

2.2 Empirical Evidence Argued to Support the Root Approach

Evidence for the alleged cognitive reality of the root comes from psycholinguistic experiments. As detailed below, previous experiments in Hebrew included various paradigms: acceptability ratings (Berent and Shimron, 1997; Berent et al., 2007), masked visual priming (Frost, Forster, and Deutsch, 1997; Velan et al., 2005), bi-modal priming (Frost et al., 2000), and rapid serial visual presentation (Velan and Frost, 2007, 2011), to name a few. All these studies aimed to validate the Root Approach, without taking into consideration the alternative, Universalist approach (with the exception of Berent et al., 2007, which compares the theories more directly).

This section summarizes the main findings from previous experiments, along with some preliminary reservations. Particular findings that are unexpected under the Root Approach are discussed in §3.

(1) PRIMING EFFECTS ACROSS MODALITIES

In visual-visual masked presentation, priming obtains with words sharing all three stem consonants (i.e., the *root* under root approaches), whether or not primes are semantically related to the target (Frost et al., 1997). For example, *taklit* *תקליט* 'record' is primed by semantically related *haklata* *הקלטה* 'recording', by semantically unrelated *klita* *קליטה* 'absorption', but not by the control *takala* *תקלה* 'error', which shares the same number of graphemes with the target.

On the other hand, in cross-modal presentation there is a gradual facilitation effect for words sharing all stem consonants. The greatest facilitation is obtained between words sharing both semantics and the three stem consonants + graphemes (which are morphologically related under both Root and Universalist Approaches), and a less but still significant facilitation is observed for words sharing all three stem consonants + graphemes, but not semantics (Frost et al., 2000). The authors argue that the results reflect a morphological effect, which cannot be reduced to semantics, orthography, and phonology. However, the control for comparison was not as phonologically and orthographically related to the targets as the "morphological" condition was, since primes were not matched for position within the word. According to recent studies on reading, the visual system identifies words based on the longest familiar sequence of graphemes that can be detected within them; very early during processing, graphemes at the beginning/end of a word that appear in this position often (i.e., affixes) are parsed as a

[3] In some approaches, e.g., Arad (2006), words are also morphological units.

separate unit (e.g., Rastle and Davis, 2008). Therefore, standardly assumed segmentation mechanisms would predict different behavior for targets that share affixal consonants with a prime, than for targets sharing stem consonants with the prime. In other words, the results could simply indicate two distinct effects, a semantic and an orthographic one. A semantic effect is reflected in the significant facilitation between semantically related and unrelated pairs – [+S] *madrix* *מדריך* 'guide' facilitates the target *hadraxa* *הדרכה* 'guidance' to a higher degree than [–S] *drixut* *דריכות* 'alertness'. An orthographic effect is reflected in the significant facilitation between words which share all stem graphemes compared with control pairs – both [+S] madrix *מדריך* 'guide' and [–S] *drixut* *דריכות* 'alertness' facilitate *hadraxa* *הדרכה* 'guidance' to a higher degree than *mehudar* מהודר 'fancy'.

(2) PRIMING WITH IRREGULAR, BI-CONSONANTAL STEMS

Words with bi-consonantal stems show two patterns of behavior, depending on their inflectional class. Some words in Hebrew lose their first stem consonant in specific configurations, due to historical reasons; this consonant is sometimes recoverable to a certain degree from the morphological paradigm. It was found that when the missing stem consonant has an ambiguous vowel/consonant status (the glide *j*), and is consequently represented as an ambiguous vowel/consonant grapheme, then using the full "root" as prime, i.e., including *j*, does not facilitate related words in masked visual priming (e.g., ***j**akar* *יקר* 'dear/expensive' does not prime *hokara* *הוקרה* 'appreciation'; Velan et al., 2005). Conversely, when the missing stem consonant is unambiguously a consonant sound, priming results are very similar to those obtained with full-paradigm tri-consonantal stems (e.g., *nafal* *נפל* 'fall' primes *mapolet* *מפולת* 'collapse'). The authors suggest that the latter effect reflects an allophonic representation of *n*-missing roots. Relying on evidence from priming experiments in Arabic (Perea et al., 2014), I suggest that visual form priming in Semitic and Indo-European languages alike relies more heavily on consonant graphemes. The apparent allophonic representation is the result of the more reliable status of consonant graphemes, combined with a gradual form similarity effect induced by the identical consonant graphemes in both prime and target.

(3) THE TRANSPOSED LETTER EFFECT

Switching positions of two adjacent consonant graphemes within a word hampers reading in Hebrew, but not in English. For example, *jugde* can easily be read as *judge* in English, while similar transpositions in Hebrew are detrimental for reading (Velan and Frost, 2007; 2011). In addition, it was found that in Hebrew, words with at least 5 graphemes which have no affixes (termed by the authors as "words without structure", e.g., *agartal* *אגרטל* 'vase') show a similar behavior to that of English words; letters in such words can be transposed with a minimal effect on reading. These findings were taken to indicate that Hebrew consonant graphemes code position more rigorously than English ones, but only when there is a "root" morpheme in the representation. That is, the orthographic representation of Hebrew readers is "deeper" than that of English readers, in the sense that it is sensitive to morphological structure. However, Perea et al. (2012) show conflicting results from Maltese, another Semitic language, which is written with Latin script and therefore has a different statistical distribution of graphemes from Hebrew and Arabic. In Maltese, words with a Semitic morphological structure can be transposed with a minimal effect on reading, as in Indo-European languages. I will argue that the writing system is the key to understanding what seems to be a more rigorous letter position encoding in Hebrew.

(4) OBLIGATORY CONTOUR PRINCIPLE (OCP) EFFECTS

Co-occurrence restrictions on the identity of consonants in Semitic words are a familiar generalization about the Semitic lexicon since Greenberg (1950). As psycholinguistic research more recently revealed, these restrictions are not merely a statistical fact about the lexicon, but (at least for Hebrew) also the result of an active constraint on the grammar. Speakers are sensitive to the distribution of stem consonants within the word, even when consonants are not adjacent (i.e., when there are intervening vowels). When a root morpheme is assumed, co-occurrence restrictions can be implemented at the root level, respecting the cross-linguistic generalization that co-occurrence restrictions apply to adjacent sounds (Shimron and Berent, 1997, 2003). A Universalist approach can account for these facts by adopting the view that consonants and vowels are represented on separate tiers (Clements, 1986), thereby explaining similar co-occurrence restrictions in other language families (e.g., Japanese), as well as vowel-dependent co-occurrence effects in Hebrew (Berent et al., 2007).

The psycholinguistic evidence summarized above challenge the Universalist Approach. If the root is not a morphological unit, why would particular co-occurrence restrictions operate at the level of stem consonants alone, in particular when they are not adjacent within the word? Why should stem consonants be such effective facilitators? The next section sketches a Universalist Approach answer.

2.3 An Alternative Interpretation: Consonants Are Privileged Phonological Units

I argue that the experimental results taken to support roots in Semitic languages reveal no more and no less than the same effects reported in other language families; namely, consonants contribute more to lexical identification, and affixes are processed before stems, in both visual and auditory presentation. Two main factors have often been neglected, which contributed to the exotic appearances of Semitic morphology at first glance: First – and this is particularly true for results of visual experiments – the distributional properties of the writing system, to be addressed in §3; and second, more generally, the different roles of consonants and vowels.

In the past decade, it has been proposed that consonants and vowels have different functions in grammar and are consequently processed differently (Nespor, Peña, and Mehler, 2003). Cross-linguistic studies of the consonant-vowel asymmetry revealed that in artificial language learning, speakers of various languages prefer to generalize over consonants when segmenting the speech stream (Bonatti et al., 2005). Speakers prefer to change vowels over consonants, both in the phonologies of their languages, as can be deduced from the typology of phonological changes, and in online reconstruction tasks (Van Ooijen, 1996; Cutler et al., 2000). The distinction between consonants and vowels is, to some extent, imported into the orthographic system (New et al., 2008; Khentov-Krauss and Friedmann, 2011). Finally, there is neurological evidence for a double dissociation between consonant and vowel recognition, suggesting they are supported by different brain areas (Carammaza et al., 2000; Poeppel, 2001).

The erroneous interpretation that most Semitic root experiments have received so far – namely, that they support the Root Hypothesis – is the result of two interrelated biases:

(1) THE ASSUMPTION OF MOST MODELS THAT PROCESSING IS UNBIASED WITH REGARD TO THE STATUS OF THE PROCESSED SEGMENTS

When a balanced lexical recognition model is assumed, in which consonants and vowels are treated in a similar fashion, a root morpheme seems necessary in order to account for the prominence of stem consonants. Conversely, adopting a model of word recognition with an inherent consonant bias makes the idea of the consonantal root unnecessary in explaining the experimental data. A consonant-biased model of speech perception, which imports this bias into the orthographic system, also offers better predictions for the results of both visual and auditory experiments in other languages.

(2) THE MERE IDEA THAT CONSONANTAL ROOTS EXIST

Postulating that the root plays a role in the lexical organization of Hebrew is the starting point for most psycholinguistic studies in Hebrew, and alternatives have not been thoroughly considered (see, however, Berent et al., 2007 and Perea et al., 2014). When taking together the results of priming studies of Semitic and non-Semitic languages, the emerging picture shows that consonants are inherently more important for lexical retrieval (and, probably, storage) in otherwise very different languages.

In order to further support these claims, I will take as a case study words which are not morphologically related under either the Root or the Universalist Approaches.

The experimental literature on Hebrew morphology, particularly in priming paradigms, considers stems that share three stem graphemes to be morphologically related (i.e., all these words have a root morpheme in common), even when the words are semantically distant and even when they are etymologically unrelated. However, words which share all three stem consonants, but not all graphemes, have not yet been considered. Such words do not share any morphological formative under either approach, since they are neither semantically nor orthographically related; the latter fact also makes them less susceptible to be perceived by speakers as etymologically/semantically related.

The relation between words which share all three stem consonants but not all graphemes thus provides the perfect phonological control for testing the unique contribution of the root in priming. If the effects found so far are indeed morphological, these pairs would be expected to show a different effect compared with pairs that share a morphological formative, i.e., share graphemes and meaning. On the other hand, if the effects found so far are phonological, as the Universalist Approach maintains, a phonological effect would be expected in the same direction for all words sharing stem consonants. The experiments presented in §3 tested three conditions, which differ on the axis of meaning [±SEMANTIC RELATION] and orthography (all 3 stem graphemes are identical vs. 1-2 letters are identical: [±ORTHOGRAPHIC RELATION], respectively), using the auditory modality. The main effect is phonological facilitation, in “root”-related and non-“root”-related pairs alike.

3 Experiments

3.1 Rationale

Most theories of morphological representations emphasize the importance of phonological form in creating morphological relations. Within theoretical linguistics, orthographic forms receive much less attention, in part because spoken/signed language is acquired without direct instruction, unlike reading, and is therefore considered to be “primary”, relying on the core mechanisms of linguistic competence, whereas reading is considered “secondary”. On the other hand, psychological models of morphological processing sometimes neglect the difference between these two formal representations altogether. As mentioned above, the role of orthographic forms in word processing has not yet been tested for Hebrew separately from phonology within the priming paradigm. Separating these factors is always difficult in alphabetic systems, since orthography was designed to represent phonological units. In Hebrew, however, it is possible due to the existence of homophonic graphemes.

Not all phonological contrasts from Tiberian Hebrew survived in Modern Hebrew (MH). Due to historical change, earlier contrastive sounds have merged, such that in MH, both *ת* and *ט* represent the sound [t], *כ* and *ק* represent [k], *ש* and *ס* represent [s] (in some cases; in others, *ש* represents [ʃ]), and *ב* and *ו* represent [v]. In addition, there is an alternation between [b] and [v], but only with [v], which is represented as *ב*. In the dialect most present in the media, *כ* [x] and *ח*[ħ] have merged, and in many dialects, *ע*, *ה*, and *א* are pronounced as null or as a glottal stop.[4] That is, in most dialects of Modern Hebrew there are segments that are phonetically indistinguishable, but have different orthographic representations, such that for two distinct letters there is only one corresponding consonant. Verbs that share a phonological “root” but not an orthographic one include pairs such as *nitpal* *נטפל* ‘harassed’ and *hitpil* *התפיל* ‘desalinated’ (where *t* is represented by different graphemes: *ט* and *ת*, respectively), as well as *hixtim* *הכתים* ‘blotted’and *xatam* *חתם* ‘signed’ (where *x* is represented by different graphemes: *כ* and *ח*, respectively).

My working assumption is that reaction time (RT) in lexical decision tasks reflects in some way the natural process of lexical retrieval. Many experiments have shown that words that are closely related semantically, associatively, or orthographically prime one another (Frost et al., 1997; Ziegler and Muneaux, 2007, among many others). In contrast, words that are only phonologically related have a facilitatory effect in early stages of processing and an inhibitory effect in later stages, an effect taken to indicate lexical competition between phonologically similar words. Before the prime is recognized, phonologically related words are still partly activated and their recognition is therefore facilitated; once the prime is recognized, inhibition begins and the recognition of phonologically related words is slower (e.g., Slowiaczek and Hamburger, 1992).[5]

To tease apart phonological and orthographic effects, the experiments utilize three basic prime-target relation types that differ on two parameters:

[4] With *ע* and *א*, in many cases no corresponding consonant exists at all. The situation with [h] is more complex: Pronunciation is affected by speech rate, word frequency, and register, in addition to inter-speaker variation.

[5] It is much less simple to determine whether and how morphological relations contribute to priming. Unlike phonological and orthographic relatedness, which can be quantified (e.g., as the number or proportion of overlapping segments), or semantic relatedness, which can be determined via a pretest, morphological relations are a matter of theoretical debate. Pairs considered as morphologically related by one scholar might be unrelated under the view of another; the case of Semitic is exactly such a case, as shown in the introduction. Further, morphological relations almost by definition overlap with semantic and phonological relatedness. It is impossible to pre-determine what the effect of morphological relation on priming should be, because there seems to be no “general case”.

(1) SEMANTIC RELATEDNESS [±S]

Most verbs in Hebrew which share all stem consonants are semantically related to some extent. However, there are different degrees of relatedness. In a semantic pretest, speakers were asked to determine the level of semantic relatedness between two verbs on a 1-5 scale. Word pairs that scored above the cutoff point of 2.5/5 were excluded as too related for [–S] pairs.). An example of a related word pair is ***he'exil*** *האכיל* 'fed'– ***'axal*** *אכל* 'ate', and an unrelated pair can be seen in ***rigel*** *ריגל* 'spied'– *hit**ragel*** *התרגל* 'got used to'.

(2) ORTHOGRAPHIC IDENTITY OF CONSONANTS [±O]

In the current design, either all stem graphemes are identical in the prime and target, as in the examples in (1), or one or two of the graphemes is different but phonetically indistinguishable (see §3.1). For example, *ʃiker* *שיקר* 'lied'– *hiʃtaker* *השתכר* 'got drunk', where the phonetically identical *k*'s correspond to different graphemes *ק* and *כ*, respectively.[6]

Table 2 provides examples for the possible relation types. Note that the parameter combination [+S,–O] is nearly impossible: It is very rare for words to sound the same, have two different graphemes representing a single sound and located in the same position, and also have similar meanings. This leaves us with 3 unique relation types. Importantly, all three relations exhibit the same degree of phonological similarity.

RELATION TYPE	PRIME		TARGET	
[+S,+O]	*sovev*	'turned *trans*.'	*histovev*	'turned *reflexive*'
[–S,+O]	*ʃalal*	'negated'	*hiʃtolel*	'gone wild'
[–S,–O]	*hiʃtatef*	'participated'	*ʃataf*	'washed'

Table 2. Conditions of the Experiment

3.2 Experiment 1

3.2.1 Stimuli and Design

For each relation type, there were two trial types: (i) experimental trials, in which prime-traget pairs were ordered in both ways (e.g., *sovev* → *histovev* and *histovev* → *sovev*), (ii) control trials for target items, with primes that were not phonologically, orthographically and semantically related (e.g., *na'al* → *histovev* and *na'al* → *sovev*). The design was therefore a within-subject 3X2X2 design: *relation type* ([+S,+O], [–S,+O], and [–S,–O]), by *relatedness* (phonologically related/unrelated) by *direction*.

All words used were verbs in the 3rd person masculine past form, which are free of inflectional suffixes. 28 verb pairs were chosen after a basic RT pretest, which served to

[6] A productive morpho-phonological process in Hebrew is metathesis, by which the consonant *t̲* of the prefix *hit* is switched with the first consonant of a stem, when the latter is a strident (*ts, s, ʃ, tʃ*): *hit̲+ʃaker* → *hiʃt̲aker* (see Bat-El, 1988). Metathesis is fully productive in *hitCaCeC*. Within stems, although it is admittedly rare, stridents may follow *t*, e.g., *hitsis* 'fermented'.

eliminate items with unusual RTs or high error rates. Attributes of the chosen items appear in the Appendix.

Two female native speakers of Hebrew, speaking in a natural rate, were recorded (ages: 25 and 27). The words were edited by a PRAAT script (Boersma, 2001) and normalized to the same volume. The resulting .wav files were used as input files for use by a PRAAT script which combined them into prime-target pairs with a stimulus onset asynchrony (SOA) of 150 ms, with the prime lowered in volume by 15 decibels and compressed to 75% of its original length. Primes and targets were presented in different voices, in order to avoid direct phonetic influence and confusion. Participants were instructed to make their judgments only regarding the second word, which might be easier when the second word is in a different voice. Four lists were created in a Latin Square design, such that a participant who was exposed to an item in one trial type would not be exposed to this item again in another trial type. In two lists, the first voice was the prime and the second – the target, and in the other two, the order of speakers was reversed.

Every participant was exposed to 168 prime-target pairs: 7 items from each of the 12 experimental conditions, and 84 in which the target was a non-word. Targets were unique, i.e., every subject gave exactly one judgement per word. Primes were used twice: once in a related condition and once in a non-word condition. Non-words shared the prosodic features of a verb in Hebrew (they appeared in a valid configuration), but their sequencing of stem consonants appears in no real verb (though they are phonotactically legal).[7]

3.2.2 Participants

Forty-eight native speakers of Hebrew participated in Experiment 1. All participants had no reported hearing problem, dyslexia, or attention disorders, and were aged 21-41 (mean = 28.48, standard deviation (SD) = 4.34). Twenty-five of them were male, and nine were left-handed. Participants were randomly assigned one of the four lists.

3.2.3 Procedure

The experiment was conducted on Psychopy, a platform for running psychological experiments (Peirce, 2007). Participants were instructed to respond as accurately and as fast as possible. They made lexical decision responses to each prime-target item by pressing the “f” key (colored red) for non-words and the “j” key (colored green) for real words. After 6 practice trials, subjects were asked to press the spacebar when they were ready to begin the experiment. Responses and reaction times were collected. Materials were presented in a different random order for each participant using Sony MDRZX100 ZX Series Stereo Headphones, on a 13-inch MacBook Air computer with 2.2 GHz Intel Core i7. The inter-trial interval was 500 ms, with a fixation cross which disappeared during stimulus auditory presentation. After 56 and 112 items, participants were given the option of taking a break, and could return by pressing the spacebar. No feedback was given.

3.2.4 Results

Only real-word trials were analyzed. Wrong responses were removed (5.6% of real-word targets). Latencies that were 2.5 SDs beyond the mean for each participant were removed as well (2.63% of the real-word trials). Short latencies were not removed, since measurement of RT was

[7] Most non-words were adapted from Fadlon (2016).

from the offset of the target, and targets could be identified before the offset, making it difficult to determine whether the fast response was authentic. Six words were excluded due to low accuracy rates (less than 70% correct identification; 2 [+S,+O], 1 [–S,+O], and 3 [–S,–O] items); their matching counterparts from all trial types were removed as well.

A response accuracy analysis was conducted after low accuracy items were removed. A 3X2 repeated measures ANOVA of *relation type* by *relatedness* revealed a main effect for *relation type* [$F(2,94) = 18.1$, $p = .001$, $\eta^2_p = .28$]. This effect is not meaningful, since it points to a difference between items in the three groups, which are different words, in both related and unrelated conditions. No interaction between *relation type* and *relatedness* was found [$F(2,94) = 1.8$, $p = .17$, $\eta^2_p = .036$], confirming that the items in each group are responsible for the main effect, and not the relation type between word pairs. A marginal main effect of *relatedness* was also observed [$F(1,47) = 3.6$, $p = .06$, $\eta^2_p = .07$]; words related to the prime by three stem consonants were on average easier to identify.

Response latencies (collapsed for both directions) are presented in Figure 1. A 3X2 repeated measures ANOVA of *relation type* by *relatedness* was employed. There was a main effect of *relation type* [$F(2,94) = 8.99$, $p < .001$, $\eta^2_p = .16$]. Although the effect for *relation type* was robust, it is not a meaningful one, since, as explained above, different materials were used for each relation type. Interaction between *relation type* and *relatedness* was not significant ($F < 1$). Participants were overall faster in the related condition vs. unrelated condition [$F(1,47) = 14.38$, $p < .001$, $\eta^2_p = .23$]. The effect was significant for all *relation types,* as revealed by the planned comparisons [+S,+O]: $F(1,47) = 7.857$, $p < .005$, $\eta^2_p = .143$, [–S,+O]: $F(1,47) = 10.04569$, $p < .005$, $\eta^2_p = .176$, [–S,–O]: $F(1,47) = 10.89306$, $p < .002$, $\eta^2_p = .188$].

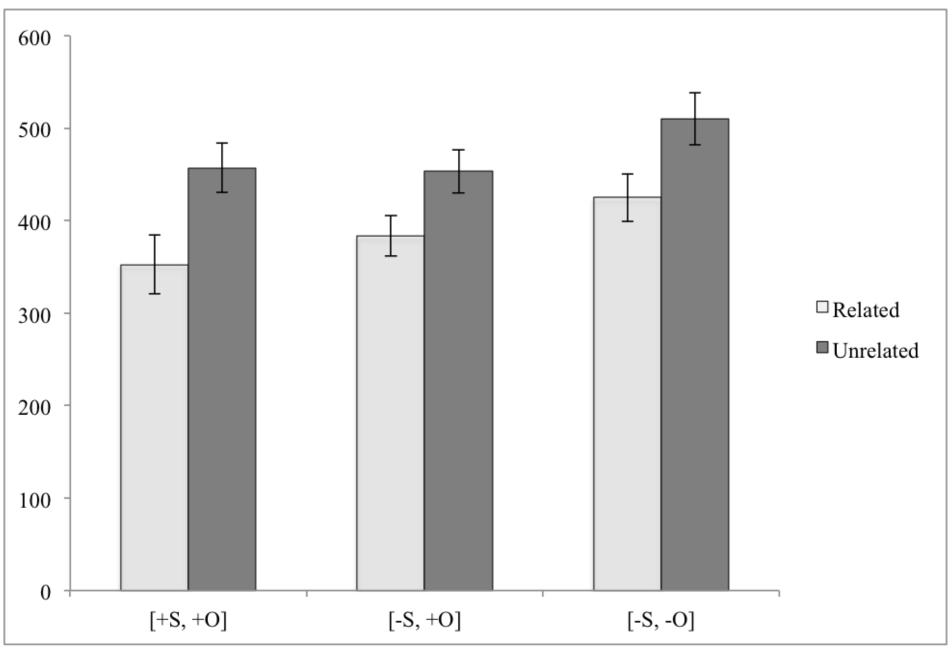

Figure 1. Mean RTs of Relation Type by Relatedness (error bars denote ±1SE)

In order to control for a possible list effect, a 3X2X4 mixed analysis ANOVA (with *relation type* and *relatedness* as within-subject factors, and *list* as a between-subject factor) was employed. The results were similar to those in the first ANOVA, with no main effect of list ($F < 1$);

additionally, an interaction was obtained between *list* and *relation type* [$F(6,88) = 5.57$, $p < .001$]. As a post-hoc analysis reveals, this interaction stems from the [–S,–O] relation type receiving longer RTs in list 1 than in all other lists [$F(1,44) = 310$, $p < .001$, $\eta^2_p = .87$].

In order to test the influence of additional consonantal segments in the prime/target on the degree of facilitation, a comparison was carried out between word pairs of which one included a prefix (*hiCCiC*, *hitCaCeC*, *niCCaC*) and the other did not (*CaCaC*, *CiCeC*). The same degree of facilitation was found with both orders, indicating that it did not matter whether the prime or the target had additional (paradigmatically given) consonants ($F < 1$).

The results of Experiment 1 revealed a major effect of phonological relatedness in all relation types. The magnitude of the effect was similar for semantically related/unrelated pairs ([+S, +O] and [+S,–O]), as well as for pairs with orthographically identical stem graphemes and pairs with 1-2 replaced homophone graphemes ([+S,–O] and [–S,–O]). A marginal main effect of relatedness was observed [$F(1,47) = 3.6$, $p = .06$, $\eta^2_p = .07$]; words related to the prime by 3 consonantal sounds were on average more easy to identify.

The results of Experiment 1 thus suggest that consonants (and particularly stem consonants) are effective facilitators: Words which share all three stem consonants facilitated each other, compared to words which share no more than one consonant.

3.3 Experiment 2

Since word processing may access multiple representations (phonological, orthographic, and semantic) at different stages, it is possible that the phonological effect obscured other, perhaps smaller, interactions with the orthographic and semantic factors. Experiment 2 was run in order to try and detect such interactions, by exposing participants to the prime for a longer time before hearing the target.

3.3.1 Stimuli and Design

The design of Experiment 2 was identical to that of Experiment 1. The stimuli were also the same, only this time prime and target volumes were similar (the prime's volume was not lowered), primes were not compressed, and the SOA (150 ms in Experiment 1) was doubled to 300 ms. The upshot of these modifications is overall longer exposure to the prime, under the assumption that different stages during word processing induce different priming effects. Particularly, in Experiment 1, lexical recognition of the prime did not necessarily take place. Sub-lexical units, i.e., consonantal phonemes would be enough to explain the facilitation pattern in Experiment 1. In order to try and force primes into being fully processed, the SOA was lengthened. When a word is recognized, the effect on recognition of the following word changes, depending, of course, on the relation between the words, and especially when the relation is phonological (Slowiaczek and Hamburger, 1992). As mentioned above, phonologically related words cause facilitation in early stages of processing and inhibition in later stages of processing. The current experiment aims to test the effect of phonological, semantic, and orthographic relations, when prime words presumably become lexically activated (contrary to Experiment 1).

3.3.2 Participants

Thirty-two native Hebrew speakers participated in Experiment 2, none of whom participated in Experiment 1. All participants had no reported hearing problems, dyslexia, or attention disorders, and were aged 20-37 (mean = 28.5, SD = 4.83). Twenty of them were female, and 6 were left-handed.

3.3.3 Procedure

Identical to Experiment 1.

3.3.2 Results

One participant was removed from the analysis due to low accuracy rates (less than 70%). Wrong responses were removed (1.21% of real-word targets). Latencies that were 2.5 SDs beyond the mean for each participant were removed (0.49% of real-word trials). Again, short latencies were not removed. The same 6 items in which performance was poor in Experiment 1 were removed as well, for the results of the two experiments to be comparable.

Results are summarized in Table 3. A 3X2 repeated measures ANOVA of *relation type* by *relatedness* was employed. Participants were overall faster in the unrelated condition, compared to the related condition [$F(1,30) = 5.3$, $p < .03$, $\eta^2_p = .61$]; that is, *relatedness* induced an inhibitory effect (cf. Experiment 1). No other main effect or interaction was found (all *F's* < 1).

RELATION TYPE	RELATED	UNRELATED
[+S,+O]	498.54 (536.61)	346.99 (171.37)
[–S,+O]	504.93 (481.22)	377.25 (231.38)
[–S,–O]	492.97 (383.51)	375.85 (192.01)

Table 3. Experiment 2: Mean RT in milliseconds (SD)

The standard deviation in related pairs seemed exceptionally large, and indeed, a closer look at the results revealed that the main inhibitory effect of phonological relatedness is subject-dependent. More particularly, the magnitude of the effect is highly correlated with RT: The slower a subject responded, the more pronounced inhibition became [[+S,+O]: $r = –.88$, $p < .05$; [+S,–O]: $r = –.74$, $p < .05$; [–S,–O]: $r = –.67$, $p < .05$]. Figure 2 includes correlation plots for all relation types (the *x* axis represents the subject's mean RT in a given condition in milliseconds; the *y* axis represents effect magnitude in milliseconds).

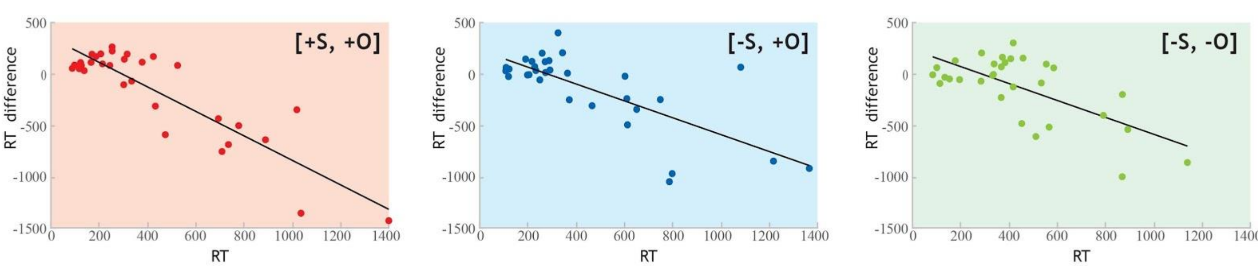

Figure 2. Correlation between mean RT per condition and magnitude of inhibition effect in milliseconds

Response accuracy analysis was conducted using a 3X2 repeated measures ANOVA of *relation type* by *relatedness*. Mauchly's test indicated that the assumption of sphericity had been violated (χ^2 = 8.09, p = .018), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity (ε = .804). A main effect for *relation type* was found [F(2,60) = 8.555, p = .001, η^2_p = .22189], parallel to the effect found with accuracy in Experiment 1 and with latencies in both experiments. The marginal main effect of *relatedness* in Experiment 1 had not been replicated [F(1,30) = .828, p = .37, η^2_p = .026]. Contrary to Experiment 1, an interaction between *relation type* and *relatedness* was found [F(2,48.26) = 6.58, p = .005, η^2_p = .1799]. That is, participants rejected a real-word target significantly more often if it was preceded by a prime which (i) shared all stem consonants with the target, and (ii) was both semantically and orthographically distant (the related [–S,–O] condition; see Table 4). Nominally, phonological relatedness enhanced accuracy in [+O] conditions in both experiments, while reducing accuracy in the [–S, –O] condition, though this difference was only statistically significant in Experiment 2.

	Relation Type	Related	Unrelated
Experiment 1	[+S,+O]	99.76%	99.03%
	[–S,+O]	98.84%	97.61%
	[–S,–O]	96.91%	97.17%
Experiment 2	[+S,+O]	100%	99.13%
	[–S,+O]	99.4%	98.45%
	[–S,–O]	97.28%	98.45%

Table 4. Average success rates per participant, Experiment 1 and Experiment 2

3.4 Discussion

The experiments were designed in order to test the effect of phonological relations in pairs of words with various semantic and orthographic relations. Overall, the phonological effect was most pronounced, yielding main effects on reaction times in both experiments. In congruence with previous studies of form priming, in auditory (Slowiaczek and Hamburger, 1992), as well as visual presentation (Gomez et al., 2013; Perea et al., 2014), short SOAs between primes and targets which are phonologically related obtained a facilitatory effect, while long SOAs obtained an inhibitory effect. Phonological consonant priming effects are predictable under a Universalist approach, which views the consonants of the stem as phonological units. If the effect were morphological, it would not be clear why morphologically unrelated words obtain similar priming effects: In the [–S,–O] condition, pairs are morphologically unrelated under all root approaches, and in the [–S,+O] condition pairs are related under a conservative Root Approach, and yet, all three conditions yielded similar results. Results from previous experiments with prime-target pairs which had similar characteristics to the [+S,+O] and [–S,+O] conditions – that is, auditorily presented materials without the orthographic manipulation (e.g., Schluter, 2013 for Moroccan Arabic) – were interpreted as support for the root's psychological status. The current experiment reinforces the claim that the effects found so far are phonological.

The accuracy data revealed a more complex pattern. In Experiment 1, a marginal phonological facilitation effect was obtained, which runs parallel to the RT results: Words that were preceded by phonologically related primes were more likely to receive a correct response, regardless of semantic and orthographic relations. On the other hand, error rates in Experiment 2 revealed a trend that was not observed in RT data: More mistakes were observed for pairs of the [–S,–O] condition. That is, with an SOA of 300 ms, it was more difficult to recognize a phonologically related word that was semantically and orthographically unrelated. This effect was not observed in [–S,+O] pairs, thereby suggesting the effect is an orthographic (and not semantic) one. It was also unobserved with [–S,–O] pairs with a 150 ms SOA (Experiment 1), suggesting that the orthography played a role mainly in later stages of processing. It might be the case that in auditory presentation, Hebrew orthography comes into play only at a relatively late stage. This direction is supported by the bi-modal study of Frost et al. (2000), which found a facilitation effect that could be attributed either to orthography or to phonology (as discussed in §2.2).

The results of phonological facilitation and no orthographic interference with a short SOA vs. phonological and orthographic inhibition with a long SOA can be interpreted as a lexical effect. Thus, the fact that inhibition of phonologically related words (all target pairs are phonologically related) and orthographically unrelated words (the [–S,–O] condition) are correlated in the time course of lexical retrieval, suggests that at some point during the 300 ms SOA, the prime was recognized. At the recognition point, the activation of neighboring representations, like those facilitated in Experiment 1, stopped, and inhibition began – of words with the same consonants, and perhaps, additionally, of words with homophonic graphemes (yielding the accuracy drop in [–S,–O] pairs). An SOA of 150 ms was not enough time for the lexical retrieval of the prime, and so the activation of the prime's phonemes spread, yielding a facilitatory effect.[8]

Under this interpretation of the results, the primes in Experiment 1 were not lexically recognized. Thus, although the primes in the current experiments were real words, experiments that use non-word priming with a similar relation to the target might nevertheless contribute to our discussion. Indeed, recent psycholinguistic experiments, inspired by Nespor et al.'s (2003) conjecture that consonants play a more important role than vowels in lexical tasks, found that non-words which include the consonants of a word facilitate that word better than non-words which include the vowels of that word, both in French and in English (e.g., for French speakers **jalu* is a better facilitator to *joli* than **vobi*). This result was found in the auditory modality (Delle Luche et al., 2014), replicating a previous result with French written words (New et al., 2008). Except for the difference in the lexical status of the primes in Delle Luche et al. and in Experiment 1 of the current study, the relation between items is fairly comparable on phonological grounds, at least for the items which do not include affixes (words which include

[8] A concern arises with respect to the procedure used in the experiment, particularly since primes were presented overtly without masking. The task, which included a quarter of phonologically related pairs (= half of the real-word trials), might have affected the manner in which participants judged the words. Non-word targets did not have consonants in common with their primes. Combined with the fact that half of the real-word pairs were phonologically related, participants could develop the following strategy: "During auditory presentation of the target, if consonants are similar to those in the prime, then the word is a real word". However, in Experiment 2, although participants had more time to develop and implement such a strategy (since the SOA was longer), the effect on RTs was in the opposite direction. This does not exclude the possibility that a strategy influenced the results of Experiment 1, but it does make this explanation far less plausible. In the same vein, it is possible that if there had been overall more phonologically unrelated real-word pairs, or better – phonologically related pairs of non-words – other interactions might have arisen.

affixes have long been known to be processed faster than morphologically simple words of the same length; e.g., Henderson et al., 1984; Bergman et al., 1988).[9]

4 Word Effects and Gradient Phonological Similarity Effects in the Psycholinguistic Literature: What a Root Approach Cannot Explain

4.1 An Outline for the Alternative

So far, the discussion focused on distinguishing the phonological status of stem consonants from the morphological status they are argued to have. The experiments described above provide evidence that words that are not morphologically related ([–S,–O] and [–S,+O] conditions) would prime one another to the same degree of morphologically related words ([+S,+O] condition) if they share all stem consonants (Experiment 1). This result weakens the claim that previously reported priming effects were morphological, and raises the question of whether phonological and orthographic relatedness were the source of previous findings as well. In what follows, I discuss data that flesh out a related empirical advantage of the Universalist Approach: its prediction of gradient similarity effect.

The first piece of evidence comes from the literature on visual word processing, an area in which, not unlike theoretical linguistics, the root debate ensues, with some theorists supporting the idea of having the root as an organizing principle of the visual word lexicon and others who support a Universalist Approach. In order to relate visual word processing in Hebrew to the same process in other alphabetic systems, let us first list factors that were shown to influence the direction and extent of priming effects in the visual modality in Indo-European languages.

(i) Early morpho-orthographic decomposition is a process that occurs in every word which incorporates affixes (Rastle and Davis, 2008). When the first or last few graphemes of a word are read more frequently as an affix, they will be segmented as an affix very early on during word recognition.

In Hebrew, affixes are often only one grapheme long. This makes the first/last grapheme ambiguous between a stem and affix status, which might result in more context-sensitive segmentation; if the consonants *n*, *m*, *h*, *t*, and *l* at the edge of a word might function as either a stem (e.g., *xalo**n*** *חלון* 'window') or an affix (e.g., *xalba**n*** *חלבן* 'milkman'), both options should be considered. This fact about the distribution of ambiguous single consonant graphemes at word edges might, in part, be responsible for some behavioral contrasts between Indo-European and Semitic readers.

(ii) The distributional properties of a language are an important factor: Neighborhood density has a crucial effect on word recognition in tasks like lexical decision, with or without a prime (McClelland and Rumelhart, 1981; Cohen et al., 2002; Dehaene et al. 2002, among many others). Dense neighborhoods have differential effects on reaction times (Binder et al., 2006), depending on at least two factors. First, the composition of the baseline to which the target words are compared changes the effect: When non-words are composed of unusual grapheme combinations (e.g., for English, **caxzaj*), increasing neighborhood

[9] Delle Luche et al. also used a very short SOA of 10 ms, in order to ensure that the primes are not processed lexically.

size is facilitatory for the word items in the task (i.e., words with more neighbors are processed faster); when non-words are composed of frequently occurring grapheme combinations (e.g., for English, **fram*), increasing neighborhood size is no longer facilitatory for the word items in the task. Second, the word frequency of the neighbor in such tasks might flip the results: When a neighbor has a higher frequency than the test item itself, the result is inhibition (*bared* would be inhibited by *beard* or *bread*).[10]

(iii) Consonants and vowels have different representations in the writing system: The consonant-vowel asymmetry discussed above seems to be carried into the orthographic system. This is reflected in online tasks in which consonant graphemes are better facilitators than vowel graphemes (Perea and Lupker, 2004; New et al., 2008; Carreiras, Duñabeitia et al., 2009; Carreiras, Seghier et al., 2009), and in the performance of individuals with Vowel Letter Dyslexia (Khentov-Kraus and Friedmann, 2011). Such speakers have trouble reading words in which a vowel letter transposition would result in a real word, e.g., *form-from*. Unlike Letter Position Dyslexia, Vowel Letter Dyslexia selectively impairs the ability to encode the position of vowel letters, compared with the position of consonant letters.[11]

The experimental evidence in favor of a root approach, which were mentioned in the introduction, boils down to some combination of the three factors above (see Berrebi, 2017). For lack of space, I will only focus on results that pose a direct empirical challenge to a root approach.

Recall that from a Universalist viewpoint, the consonants of the stem are individual phonological units. They can be submitted to a particular rule throughout the domain of a word (e.g., co-occurrence restriction) by virtue of their common phonological features, via feature geometry. At no point, however, is a “vowel-free” morphological representation of consonants invoked. In contrast, according to the Root Approach, the stem consonants of a word form an atomic unit, of which the lexicon is composed. The consonantal root is an indivisible entity, which binds under a single lexical entry every word that shares it. During word processing, words are decomposed into their morphological subunits: root and configuration. The root (= stem consonants) is the main key to lexical recognition in all domains of grammar, while configurations are more useful for retrieval in the verbal system than in the nominal system (Frost et al., 2005).

Two experiments were particularly efficient in fleshing out the distinction between the Root Approach and the view that word recognition is based on form similarity and consonant grapheme superiority, as in Indo-European languages. The first addressed the lack of the transposed letter effect in Hebrew (Velan and Frost, 2007, 2011), i.e., the fact that letter transposition in Hebrew is detrimental to reading, unlike in Indo-European languages. The second, described in §4.3, studied the psychological status of co-occurrence restriction in Hebrew, which also appear to be gradient and word-based.

[10] Most words, as well as legal non-words in Hebrew, have dense neighborhoods, due to (i) under-representation of vowels in the orthographic system, which results in typically very short consonant-only graphemic representation, and (ii) prosodic restrictions: Both verbs/verbal and native nouns/nominal lexical items are 2-3 syllables long.. This results in a very limited set of phonological word sizes, which correlates with orthographic length.

[11] Importantly, vowel and consonant graphemes in Hebrew do not categorically vary in size or visual complexity, so the effect seems to be due to the phonological nature of the represented phones.

4.2 Gradient Phonological Similarity Effects in Semitic

For some scholars, the transposed letter effect provides further support for the claim that the lexical organization of Indo-European languages is qualitatively different from the reading mechanism and lexical organization in Semitic languages (among others, Frost et al., 1997; Deutsch et al., 2000; Frost, 2012). Others have suggested that the divergence between form-related priming in Indo-European languages vs. apparent morphological-related priming in Semitic is the result of purely statistical facts about the distribution of consonants within lexical items in the two language families. That is, the languages and reading mechanisms are not qualitatively different; the difference is at the quantitative level (e.g., Davis, 2012; Whitney, 2012).

Perea et al. (2014) found a test case for which these different approaches diverge. They observed that while the distributional properties of Semitic languages are such that transposing two letters within a word is very likely to create a new word (contrary to Indo-European languages), replacing a letter has about the same chance of creating another word in both language families. Based on a neural network simulation presented in Lerner et al. (2014), Perea et al. point out that a neural network which learned an English lexicon and one which learned a Hebrew lexicon had a high degree of overlap in representation between switched letter pairs, while the English neural network had a much greater overlap between representations of transposed-letter items.

The fact that both networks demonstrated comparable performances in switched-letter words, allows us to test the hypothesis that the reason for divergence with regard to transposed words was due to distributional facts. More interestingly, a partial form overlap in Hebrew is predicted to have no effect under the assumption that priming relies on the morphological organization of the language. As discussed above, under the Root Approach, the root is a whole, abstract unit, which does not have sub-parts. Thus, every form priming effect that is based on partial overlap between consonants cannot be attributed to the root, and provides support for the reanalysis of “root” priming effects as a combination of form similarity and the distributional properties of graphemes within words.

In their series of priming experiments, Perea et al. (2014) showed that in Arabic, switched letter pairs significantly prime each other (**kxab* primes *ktab* ‘write’), as expected under the form-priming approach but not under the hypothesis that root priming is the crucial factor in Semitic. In fact, their elaborate predictions allowed us to find a similar result in a previous experiment by Velan and Frost (2011), where similar materials induced a facilitation effect (**taʃmil תשמיל** primes *tarmil תרמיל* ‘backpack’; experiment 4). While the results for “productive” roots in Hebrew did not show the same effect (i.e., words with very dense neighborhoods did not benefit from early exposure to their switched-letter counterparts), these results suggest that a more careful selection of materials would reveal similar effects.

In their studies of letter position encoding in Semitic (Arabic: Perea et al., 2014; Maltese: Perea et al., 2012) and non-Semitic languages (Spanish: Perea and Lupker, 2004; Thai: Winskel and Perea, 2013), Perea and colleagues advance a similar hypothesis to the one I advance here, namely, that the difference between Semitic and non-Semitic is not qualitative (i.e., different building blocks/mental organization) but quantitative (i.e., arising from the particular distribution of consonants and vowels in words). By comparing the priming effects obtained for different languages, with careful selection of items and relations that are indeed equivalent in the chosen languages, they provide a unified account for what seems at first glance like irreconcilable behavioral results.

4.3 A Stem Representation in Co-occurrence Restrictions

The second point to undermine the atomicity of the root is the famous case of co-occurrence restrictions in Semitic (Greenberg, 1950), which were shown to be an active constraint in the grammar of Hebrew speakers (e.g., Shimron and Berent, 1997, 2003). Under a Universalist approach, the relative independence of consonants and vowels in Semitic languages is explained within the framework of Feature Geometry (Clements, 1986). In Feature Geometry, phonological features are organized on autosegmental tiers. What happens on one tier does not affect others; a feature can thus bind non-neighboring segments within a word or a stem into a sort of functional unit. Segments that belong to the same tier (i.e., share a feature) can affect each other throughout a domain, such as a word. Feature Geometry is independently motivated by phenomena such as vowel and sibilant harmony. Bat-El (2003) advances the view that OCP effects in Hebrew should be dealt with using the same mechanism, as the case of co-occurrence restrictions on consonants is formally similar.

In addition to the theoretical advantage of relying on individually supported mechanisms for deriving Greenberg's generalization, the Universalist Approach makes the prediction that languages from other language families may also exhibit similar consonant-specific co-occurrence restrictions. This is because the phonological representation under feature geometry can apply differently to consonants and vowels. This prediction is borne out: Japanese presents an OCP effect on Yamato stems. Similarly to Hebrew and Arabic, the number of observed consonants with the same place of articulation within a stem (labial-labial, coronal-coronal, dorsal-dorsal) is far below the expected value if there were no restriction (Kawahara et al., 2006).

There is also evidence that co-occurrence restrictions in Hebrew apply differently in different domains of the lexicon. Such evidence is of particular importance, since it cannot be easily attributed to a root morpheme. In a series of grammaticality judgment tests, Berent, Vaknin, and Marcus (2007) offer a fresh look on OCP effects in Semitic. If the co-occurrence restriction *XYZ*>*XYY*>*XXY* is instantiated at the level of the root, they argue, it should not matter which vowels intervene between the root consonants; *XeYeY* and *XiYuY* are formally similar, as far as the root is concerned. On the other hand, the Universalist Approach suggests that the lexicon (of all languages, not only Semitic) stores *stems* – representations that include intervening vowels. Since vowels are included in the representation of stems, and co-occurrence restrictions are instantiated over stems, the Universalist Approach predicts that intervening vowels could, in principle, strengthen/weaken the effect of OCP. *XeYeY* stems are much less common in the lexicon than *XiYuY* stems, allowing a direct examination of the hypotheses: If OCP applies to roots, no difference is expected between *XeYeY* and *XiYuY* type words; if OCP applies to stems, *XeYeY* type words are expected to be less acceptable than *XiYuY* type words, in accordance with the relative amount of stored lexical items of these forms, respectively. The latter prediction turned out to be correct, both in offline judgment tasks, where subjects rated items of the types *XiXuY*, *XiYuY*, *XiYuZ*, and *XeXeY*, *XeYeY*, *XeYeZ*, consistently rating *XiYuY* as better than XeYeY compared with their respective *XYZ* counterparts; and in an online lexical decision task, in which it took longer for speakers to decide that a *XiYuY*-type item was a non-word than it did for a *XeYeY*-type item. As the authors point out, this does not mean that the OCP is not active at both levels; it merely means that the OCP must operate at the stem level. In any case, these pieces of evidence suggest that while the consonants of the stem are at the heart of the Semitic OCP constraint, vowels have a role in it as well, in line with the hypothesis that stems are stored as a whole.

In sum, we saw that co-occurrence restrictions in Hebrew can be explained under the Semitic-specific Root Approach: OCP operates at the root level. It is accounted for equally well under a Stem Approach: OCP applies only to the consonants of the stem; this is based on the Feature Geometry assumption that segments with similar features can be bound together throughout a domain. While both approaches account for the Semitic facts, the Universalist Approach is also able to account for co-occurrence restrictions in Yamato stems. Furthermore, Berent et al.'s (2007) experiments revealed that Greenberg's generalization must be implemented (at least, if not only) as a gradual constraint at the level of stems. The psychological evidence supports the existence of a stem-level representation in which OCP applies, and contradict the claim that only a root-level explanation of the effect is viable.

5 Conclusions

In this article, I claimed that there is no psycholinguistic evidence for the existence of a consonant-only unit that organizes the Hebrew lexicon. While consonants are indeed more important than vowels for lexical retrieval, this tendency is both universal and phonological. It is universal in that it is also true for other language families, and it is phonological because it is not affected by semantic and orthographic similarities in early stages of processing. In addition, consonant grapheme facilitation is exhibited with partial form overlap, contrary to the atomicity prediction of the Root Approach.

References

Anderson, Stephen R. 1992. *A-morphous morphology*. Cambridge: Cambridge University Press.

Arad, Maya. 2005. *Roots and patterns: Hebrew morphosyntax*. Berlin: Springer.

Aronoff, Mark. 1976. *Word Formation in Generative Grammar*. Cambridge, Mass.: MIT Press.

Bat-El, Outi. 1988. Remarks on tier conflation. *Linguistic Inquiry* 19.3:477–485.

Bat-El, Outi. 1994. Stem Modification and Cluster Transfer in Modern Hebrew. *Natural Language and Natural Linguistic Theory* 12.4:571–96.

Bat-El, Outi. 2003. Semitic verb structure within a universal perspective. In *Language Processing and Acquisition in Languages of Semitic, Root-based, Morphology*, ed. Joseph Shimron, 29–59. Amsterdam: John Benjamins.

Berent, Iris, and Joseph Shimron. 1997. The representation of Hebrew words: Evidence from the obligatory contour principle. *Cognition* 64.1:39–72.

Berent, Iris, Vered Vaknin, and Gary F. Marcus. 2007. Roots, stems, and the universality of lexical representations: Evidence from Hebrew. *Cognition* 104.2:254–286.

Bergman, Marijke W., Patrick T. W. Hudsonxs, and Paul A. T. M. Eling. 1988. How simple complex words can be: Morphological processing and word representations. *The Quarterly Journal of Experimental Psychology* 40.1:41–72.

Berrebi, Si. 2017. *The Roots of Consonant Bias: A Psycholinguistic Study of Phonological Facilitation in Hebrew*. Ms., Tel Aviv University.

Binder, Jeffrey R., David A. Medler, Chris F. Westbury, Einat Liebenthal, and Lori Buchanan. 2006. Tuning of the human left fusiform gyrus to sublexical orthographic structure. *Neuroimage* 33.2:739–748.

Boersma, Paul. 2001. Praat, a system for doing phonetics by computer. *Glot International* 5.9/10:341–345.

Bonatti, Luca L., Marcela Peña, Marina Nespor, and Jacques Mehler. 2005. Linguistic constraints on statistical computations: The role of consonants and vowels in continuous speech processing. *Psychological Science* 16:451–459.

Caramazza, Alfonso, Doriana Chialant, Rita Capasso, and Gabriele Miceli. 2000. Separable processing of consonants and vowels. *Nature* 403:428–430.

Carreiras, Manuel, Jon Andoni Duñabeitia, and Nicola Molinaro. 2009. Consonants and vowels contribute differently to visual word recognition: ERPs of relative position priming. *Cerebral Cortex* 19.11:2659–2670.

Carreiras, Manuel, Mohamed L. Seghier, Silvia Baquero, Adelina Estévez, Alfonso Lozano, Joseph T. Devlin, and Cathy J. Price. 2009. An anatomical signature for literacy. *Nature* 461:983–986.

Clements, George N. 1985. The geometry of phonological features. *Phonology* 2.1:225–252.

Cohen, Laurent, Stéphane Lehéricy, Florence Chochon, Cathy Lemer, Sophie Rivaud, and Stanislas Dehaene. 2002. Language-specific tuning of visual cortex? Functional properties of the Visual Word Form Area. *Brain* 125:1054–1069.

Cutler, Anne, Nuria Sebastián-Gallés, Olga Soler-Vilageliu, and Brit Van Ooijen. 2000. Constraints of vowels and consonants on lexical selection: Cross-linguistic comparisons. *Memory & Cognition* 28:746–755.

Davis, Colin J. 2012. Developing a universal model of reading necessitates cracking the orthographic code. *Behavioral and Brain Sciences* 35:283–284.

Dehaene, Stanislas, Gurvan Le Clec'H, Jean-Baptiste Poline, Denis Le Bihan, and Laurent Cohen. 2002. The visual word form area: A prelexical representation of visual words in the fusiform gyrus. *NeuroReport* 13.3:321–325.

Delle Luche, Claire, Silvana Poltrock, Jeremy Goslin, Boris New, Caroline Floccia, and Thierry Nazzi. 2014. Differential processing of consonants and vowels in the auditory modality: A cross-linguistic study. *Journal of Memory and Language* 72:1–15.

Frost, Ram. 2012. A universal approach to modeling visual word recognition and reading: Not only possible, but also inevitable. *Behavioral and Brain Sciences* 35:310–329.

Frost, Ram, Avital Deutsch, Orna Gilboa, Michal Tannenbaum, and William Marslen-Wilson. 2000. Morphological priming: Dissociation of phonological, semantic, and morphological factors. *Memory & Cognition* 28:1277–1288.

Frost, Ram, Kenneth I. Forster, and Avital Deutsch. 1997. What can we learn from the morphology of Hebrew? A masked-priming investigation of morphological representation. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 23:829-856.

Frost, Ram, Tamar Kugler, Avital Deutsch, and Kenneth I. Forster. 2005. Orthographic structure versus morphological structure: Principles of lexical organization in a given language. *Journal of Experimental Psychology: Learning, Memory and Cognition* 31:1293–1326.

Gomez, Pablo, Manuel Perea, and Roger Ratcliff. 2013. A diffusion model account of masked versus unmasked priming: Are they qualitatively different? *Journal of Experimental Psychology: Human Perception and Performance* 39:1731–1740.

Grainger, Jonathan, and Johannes C. Ziegler. 2011. A dual-route approach to orthographic processing. *Frontiers in Psychology* 2:54.

Greenberg, Joseph H. 1950. The patterning of root morphemes in Semitic. *Word* 6.2:162–181.

Heath, Jeffrey. 2003. Arabic derivational ablaut, processing strategies, and consonantal “roots”. In *Language Processing and Acquisition in Languages of Semitic, Root-Based, Morphology*, ed. Joseph Shimron, 201–222. Amsterdam: John Benjamins.

Henderson, Leslie, Julie Wallis, and Denise Knight. 1984. Morphemic structure and lexical access. *Attention and Performance* 10:211–226.

Kawahara, Shigeto, Hajime Ono, and Kiyoshi Sudo. 2006. Consonant co-occurrence restrictions in Yamato Japanese. *Japanese/Korean Linguistics* 14:27–38.

Khentov-Kraus, Lilach, and Naama Friedmann. 2011. Disleksyat koshi be-imot kri’a (kbak) [Dyslexia in vowel letters (DIVL)]. *Safa va-mo’ax* [*Language and Brain*] 10:65-106. [in Hebrew]

Lerner, Itamar, Blair C. Armstrong, and Ram Frost. 2014. What can we learn from learning models about sensitivity to letter-order in visual word recognition? *Journal of Memory and Language* 77:40–58.

McCarthy, John. 1979. *Formal Problems in Semitic Phonology and Morphology*. Doctoral Dissertation, MIT, Cambridge, Mass.

McClelland, James L., and David E. Rumelhart. 1981. An interactive activation model of context effects in letter perception: Part 1. An account of basic findings. *Psychological review* 88.5: 375–407.

Moscati, Sabatino. 1980. *An Introduction to the Comparative Grammar of the Semitic Languages: Phonology and Morphology*. Wiesbaden: Otto Harrassowitz.

Nespor, Marina, Marcela Peña, and Jacques Mehler. 2003. On the different roles of vowels and consonants in speech processing and language acquisition. *Lingue e linguaggio* 2:203–230.

New, Boris, Verónica Araújo, and Thierry Nazzi. 2008. Differential processing of consonants and vowels in lexical access through reading. *Psychological Science* 19:1223–1227.

Peirce, Jon. 2007. PsychoPy - Psychophysics software in Python. *Journal of Neuroscience Methods* 162:8–13

Perea, Manuel, Reem Abu Mallouh, and Manuel Carreiras. 2010. The search for an input-coding scheme: Transposed-letter priming in Arabic. *Psychonomic Bulletin & Review* 17:375–380.

Perea, Manuel, Reem Abu Mallouh, and Manuel Carreiras. 2014. Are root letters compulsory for lexical access in Semitic languages? The case of masked form-priming in Arabic. *Cognition* 132:491–500.

Perea, Manuel, Albert Gatt, Carmen Moret-Tatay, and Ray Fabri. 2012. Are all Semitic languages immune to letter transpositions? The case of Maltese. *Psychonomic Bulletin & Review* 19:942–947.

Perea, Manuel, and Stephen J. Lupker. 2004. Can CANISO activate CASINO? Transposed-letter similarity effects with nonadjacent letter positions. *Journal of Memory and Language* 51:231–246.

Poeppel, David. 2001. Pure word deafness and the bilateral processing of the speech code. *Cognitive Science* 25:679–693.

Prince, Alan. S. 1980. A metrical theory for Estonian quantity. *Linguistic Inquiry* 11:511–562.

Prunet, Jean-François, Renée Béland, and Ali Idrissi. 2000. The mental representation of Semitic words. *Linguistic Inquiry* 31.4:609–648.

Rastle, Kathleen and Matthew H. Davis. 2008. Morphological decomposition based on the analysis of orthography. *Language and Cognitive Processes* 23:942–971.

Berent, Iris, and Joseph Shimron. 1997. The representation of Hebrew words: Evidence from the obligatory contour principle. *Cognition* 64:39–72.

Schluter, Kevin. 2013. *Hearing words without structure: Subliminal speech priming and the organization of the Moroccan Arabic lexicon*. Doctoral Dissertation, University of Arizona.

Shimron, Joseph and Berent, Iris. 2003. What is a Root? In *Language Processing and Acquisition in Languages of Semitic, Root-Based, Morphology*. ed. Joseph Shimron, 201–222.
Amsterdam: John Benjamins.

Slowiaczek, Louisa M. and Mary Beth Hamburger. 1992. Prelexical facilitation and lexical interference in auditory word recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 18:1239–1250.

Ussishkin, Adam. 1999. The inadequacy of the consonantal root: Modern Hebrew denominal verbs and output-output correspondence. *Phonology* 16:401–442.

Ussishkin, Adam. 2000. *The Emergence of Fixed Prosody*. Doctoral Dissertation, UCSC.

Van Ooijen, Brit. 1996. Vowel mutability and lexical selection in English: Evidence from a word reconstruction task. *Memory & Cognition* 24, no. 5:573–583.

Velan, Hadas and Ram Frost. 2007. Cambridge University Vs. Hebrew University: The impact of letter transposition on reading English and Hebrew. *Psychonomic Bulletin and Review* 14:913–918.

Velan, Hadas. and Ram Frost. 2009. Letter-transposition effects are not universal: The impact of transposing letters in Hebrew. *Journal of Memory and Language* 61:285–302.

Velan Hadas. and Ram Frost. 2011. Words with and without internal structure: What determines the nature of orthographic processing. *Cognition* 118:141–156.

Velan, Hadas, Ram Frost, Avital Deutsch, and David C. Plaut. 2005. The processing of root morphemes in Hebrew: Contrasting localist and distributed accounts. *Language and Cognitive Processes* 20:169–206.

Whitney, Carol. 2012. The study of orthographic processing has broadened research in visual word recognition. *Behavioral and Brain Sciences* 35:309–310.

Winskel, Heather and Manuel Perea. 2013. Consonant/vowel asymmetries in letter position coding during normal reading: Evidence from parafoveal previews in Thai. *Journal of Cognitive Psychology* 25:119–130.

Ziegler, Johannes C. and Mathilde Muneaux. 2007. Orthographic facilitation and phonological inhibition in spoken word recognition: A developmental study. *Psychonomic Bulletin & Review* 14:75–80.

Appendix

Table 5 provides the attributes of the items in Experiments 1 and 2. The full set of materials is available at: https://drive.google.com/open?id=1PrG1FcWy5jscGJScUoecSXthPhyHLjp_.

		List 1	
		Experimental	Control
[+S,+O]	*Mean Semantic Relatedness Score*	3.774/5 (SD = .2)	not rated
	Mean Number of Syllables in Prime	2.339 (SD = .482)	2.268 (SD = .447)
	Mean Number of Syllables in Target	2.339 (SD = .482)	2.089 (SD = .288)
	Shared Consonants	2.944 (SD = .333)	0.893 (SD = .802)
	Unique Consonants	1.472 (SD = .609)	5.446 (SD = 1.249)
[–S,+O]	*Mean Semantic Relatedness Score*	1.591/5 (SD = .4)	not rated
	Mean Number of Syllables in Prime	2.304 (SD = .464)	2.393 (SD = .493)
	Mean Number of Syllables in Target	2.304 (SD = .464)	2.321 (SD = .471)
	Shared Consonants	3 (SD = .471)	0.589 (SD = .708)
	Unique Consonants	1.25 (SD = .7)	6.143 (SD = 1.47)
[–S,–O]	*Mean Semantic Relatedness Score*	1.207/5 (SD = .2)	not rated
	Mean Number of Syllables in Prime	2.196 (SD = .387)	2.107 (SD = .312)
	Mean Number of Syllables in Target	2.196 (SD = .387)	2.232 (SD = .426)
	Shared Consonants	2.857 (SD = .448)	0.536 (SD = .602)
	Unique Consonants	1.036 (SD = .693)	5.893 (SD = 1.107)

Table 5. Attributes of items by condition