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Universal and particular in morphological processing: Evidence from Hebrew

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Abstract

Do properties of individual languages shape the mechanisms by which they are processed? By virtue of their non-concatenative morphological structure, the recognition of complex words in Semitic languages has been argued to rely strongly on morphological information and on decomposition into root and pattern constituents. Here, we report results from a masked priming experiment in Hebrew in which we contrasted verb forms belonging to two morphological classes, Paal and Piel, which display similar properties, but crucially differ on whether they are extended to novel verbs. Verbs from the open-class Piel elicited familiar root priming effects, but verbs from the closed-class Paal did not. Our findings indicate that, similarly to other (e.g., Indo-European) languages, down-to-the-root decomposition in Hebrew does not apply to stems of non-productive verbal classes. We conclude that the Semitic word processor is less unique than previously thought: Although it operates on morphological units that are combined in a non-linear way, it engages the same universal mechanisms of storage and computation as those seen in other languages.

Keywords

Language universals; morphology; priming; Semitic

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How do properties of individual languages shape supposedly universal mechanisms of language processing? In the current study, this question is investigated with respect to morphology, a common source of cross-linguistic variability. Languages differ considerably in the ways in which they express morphosyntactic information—for example, via concatenative structures (e.g., *walk+ed*), marked stems (e.g., Portuguese: *fiz-* "did"), or periphrasis (e.g., Vietnamese: *đã đi* "went"). For experimental psycholinguistics, such variability raises the question of how the mental representation and processing of complex words are affected by properties of individual languages (e.g., Bick, Goelman, & Frost, 2011; Frost, Forster, & Deutsch, 1997). Specifically, mechanisms of word recognition might differ across languages, directly reflecting this cross-linguistic variability, or instead, might be abstract and general enough to apply to different kinds of morphological encoding.

Experimental studies of Semitic languages, like Hebrew and Arabic, have featured prominently in this debate, by virtue of their salient and pervasive *non-concatenative* morphology. That is, besides the linear combination of stems and affixes that is common in many languages, the formation of stems in Semitic languages involves the non-linear combination of consonantal *roots*, carrying core meaning, and vowel *patterns*, which may also express grammatical information (e.g., Hebrew: *L-M-D+taC-CiC=talmid* "pupil"). It has been proposed that this property drives the Semitic lexical processor to be primarily "morphological" in nature, designed to extract a complex word's abstract structure (root and word pattern), irrespective of meaning or surface form (Boudelaa & Marslen-Wilson, 2015; Frost et al., 1997). By contrast, the word recognition system of Indo-European languages, such as English, is thought to be less purely driven by morphology, but instead more affected by factors such as semantic transparency and orthographic similarity (Velan & Frost, 2011). For example, while semantically opaque forms in English (e.g., *business–busy*) typically do not produce morphological facilitation effects in overt priming experiments (e.g., Gonnerman, Seidenberg, & Andersen, 2007; Marslen-Wilson, Tyler, Waksler, & Older, 1994), in

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Hebrew and Arabic, morphological priming is also obtained between opaque forms that share a root (Boudelaa & Marslen-Wilson, 2005; Frost, Deutsch, Gilboa, Tannenbaum, & Marslen-Wilson, 2000).

According to Bick et al. (2011), the contrast between experimental effects in English and Semitic arises because word forms in English often cannot be straightforwardly mapped onto morphemes (e.g., {business} ≠ {busy} + {-ness}), whereas in Semitic languages almost all words are morphologically structured. Therefore, the extraction of root information provided by full morphological parsing ("down-to-the-root") is thought to be a main priority of the Semitic lexical processor (e.g., Boudelaa & Marslen-Wilson, 2011, 2015). Alternatively, in distributed connectionist accounts, morphological knowledge is represented as associations between full forms and their meanings (Gonnerman et al., 2007), such that languages with more inconsistent form-to-meaning mappings (i.e., languages with a "richer" morphology, such as Semitic) are supposed to show stronger morphological effects that are less dependent on semantics (Plaut & Gonnerman, 2000).

Against this background, the present study examines inflected verb forms in Hebrew, which have previously been claimed to be morphologically represented and fully decomposed into roots and patterns in lexical access (e.g., Deutsch, Frost, & Forster, 1998). Following much previous research, we employed the masked priming paradigm, a technique that has been found to be particularly sensitive to morphological structure (e.g., Frost et al., 1997; Marslen-Wilson, 2007). We specifically investigated root-priming effects from inflected forms of different Hebrew verbal classes called *binyanim* (singular: binyan). Although morphemic decomposition (as revealed by root-priming effects) has been argued to be the primary step of Hebrew word recognition, no study has examined potential differences between the various Hebrew verbal classes in the process of word recognition.

To preview, our findings provide only partial support for a down-to-the-root-parsing approach in Hebrew. Whilst complex forms that belong to an "open class" (i.e., that contain a productive word pattern) were indeed found to be fully decomposed, this was not the case for inflected verb forms that belong to a "closed class" that does not extend to new verbs. We will conclude that the Semitic morphological processing system is less unique than previously thought. Although Semitic languages employ non-concatenative root-and-pattern combinations, they nevertheless show the same alignment between productivity and decomposition that is seen in many other languages.

Hebrew verbal morphology

There are seven verbal classes or binyanim in Hebrew, defined by their particular vowel patterns. As mentioned above, these vowel patterns combine non-linearly with the consonants of the root, such that both root and pattern surface in a discontinuous way. Furthermore, the same root sometimes appears in more than one verbal class, creating different verbs. For example, verbs of the binyan "Paal" display the pattern *CaCaC*,[1] which when combined with the root *L-M-D* yields the verb *lamad* "he learned". In another binyan, "Piel", the same root is combined with the pattern *CiCeC*, to yield a verb with a different meaning, *limed* "he taught". Although the Hebrew binyanim display certain regularities that suggest abstract syntactic and semantic properties, only two binyanim (Pual and Hufal) are completely predictable (as passive analogues of two other binyanim). The other five show only tendencies that are far from deterministic (for review, see Arad, 2005). In fact, many verbs have highly lexicalized meanings, which are generally difficult or impossible to compute compositionally on the basis of individual roots and patterns. Furthermore, the system is "filled with holes" (Aronoff, 1994, p. 124), with almost no roots occurring in all binyanim. Such properties invite a treatment of the Hebrew binyanim as an example of derivational morphology (Waltke & O'Connor, 1990), but Aronoff notes that binyanim assignment differs from derivation by being obligatory. That is, while underived lexemes exist in every language, Hebrew verbs cannot exist just as roots and have to be assigned to a binyan in order to be properly inflected. Since binyan membership determines the particular shape of every form of a verb, but does not clearly encode specific syntactic or semantic properties, the Hebrew binyanim are not morphemes in any meaningful sense, but are better conceived of as abstract morphological categories.

The present study

The current study contrasts priming effects produced by verbs of the Paal and Piel binyanim, two verb classes that display comparable type frequencies and that, as a whole, are similar in terms of the general syntactic and semantic properties of their verbs (see Table 1). Nevertheless, there is a striking difference between the two: The Paal binyan constitutes a closed class, which "plays no role at all in the formation of new verbs", whereas Piel is readily extended and, in fact, "the most important binyan for forming new verbs" (Aronoff, 1994, p. 130). This difference has been demonstrated, for example, by the longitudinal examination of neologisms, as well as in elicited production experiments (Bolozky, 1999).

From a dual-morphology perspective (e.g., Clahsen, 1999; Pinker, 1999), the discrepancy in the productivity of Paal and Piel points to possible representational differences, particularly with regard to the contrast between structured and undecomposed stems. Highly productive morphological operations—which extend readily to novel items—are likely to be *rule based*. That is, they are the

Table 1. Properties of the Paal and Piel verb classes.

Binyan	Phonological base form	Example	Semantic properties	Type frequency %
Paal	*CaCaC*	*lamad* "learned"	active	19.4
Piel	*CiCeC*	*limed* "taught"	active	17.1

Note: The type frequency percentages were calculated from a corpus containing 4,131 verbs (Itai & Wintner, 2008).

result of operations over variables, placeholders that stand for whole grammatical categories like "verbal root" (Marcus, 2001; Pinker & Ullman, 2002; Veríssimo & Clahsen, 2014). At the same time, rules are combinatorial operations that generate structured representations and that can be employed in processing to (de)compose stems and word forms from (or into) their morphological constituents. The link between productivity and constituent structure can be seen across language families and morphological operations. A case in point is regular inflection in Germanic languages (e.g., the English *-ed* past tense), which generalizes widely to novel verbs and produces experimental effects that are indicative of structured representations, such as robust priming on the recognition of their bases (e.g., Marslen-Wilson & Tyler, 1998; Newman, Ullman, Pancheva, Waligura, & Neville, 2007; Stanners, Neiser, Hernon, & Hall, 1979). Another example, closer to the Hebrew binyanim, comes from languages with conjugation classes. In Portuguese, for example, the class that extends to novel verbs also displays priming effects that indicate down-to-the-root decomposition (Veríssimo & Clahsen, 2009). In contrast, members of unproductive classes—which only rarely welcome new members—are predicted by dual-morphology accounts to be lexically stored as exceptions to general morphological rules. Therefore, they do not activate their roots "directly", via decomposition into morphological constituents, but are instead argued to involve whole-form access and processing. Accordingly, such forms typically produce reduced priming effects on their bases, even when they are phonologically and semantically transparent (e.g., Sonnenstuhl, Eisenbeiss, & Clahsen, 1999; Stanners et al., 1979; Veríssimo & Clahsen, 2009).[2] Within Semitic languages, further support for the relationship between pattern productivity and morphological constituency comes from a recent study by Wray (2016) with Arabic speakers. In a series of auditory lexical decision experiments, response times for forms belonging to both productive and non-productive binyanim were found to be predicted by word-form frequency, whereas only the recognition of productive binyanim was predicted by the frequency of the root.

If the rationale that we have laid out applies to Hebrew verb forms, then genuine root-priming effects (signalling full morphemic decomposition) should be restricted to verbs of open classes, like the Piel binyan. Conversely, we hypothesized that verbal stems belonging to a closed class, like Paal, are not related to their roots by rule, but are accessed via an unstructured stem representation. If that is the case, they should fail to produce the typical root-priming effect that has been observed in previous priming studies in Semitic (e.g., Boudelaa & Marslen-Wilson, 2015; Deutsch et al., 1998).

Since the same root can appear in different binyanim, Hebrew allows the opportunity to compare priming effects elicited by different verbal classes (Paal and Piel) on the very same target words. In the current study, targets were verbs belonging to the Hitpael binyan that share a root with their morphologically related (Paal or Piel) primes. Hitpael verbs were used as targets, because (a) they display a pattern that is productive in new word formation (Bolozky, 1999), (b) their forms are not homographic with other verbal forms, and (c) Hitpael verbs do not have a systematic or predictable semantic relation to either Paal or Piel verbs.[3]

Two sets of items were included in the present experiment, one set in which targets were preceded by primes in the first-person singular past form (1sg past), and another for which primes were presented in the infinitive (infinitive condition). This allowed us to assess the replicability of priming effects across items, by examining whether the same contrasts were obtained with another set of target words, as well as with primes presented in a different verbal form. In addition, these specific verbal forms were selected to control for possible orthographic effects. All primes–target triplets shared three consonant letters (the root), but 1sg past forms of Piel verbs contained an additional letter (a vowel) that was not present in Hitpael targets; for primes presented in the infinitive, it was instead the Paal forms that contained an additional letter.

Method

Participants

Thirty native speakers of Hebrew (20 females, 3 left-handed) between the ages of 18 and 37 years (mean: 28.75 years) participated in the experiment. All participants were born in Israel, had completed at least 12 years of education, and used spoken and written Hebrew on a daily basis. They all had normal or corrected-to-normal vision, and none had been diagnosed with any language disorders.

Materials

Table 2 displays the experimental design, including an example stimulus set. Experimental targets consisted of 42

Table 2. Experimental conditions, with an example stimulus set.

Form	Prime			Target (Hitpael)
	Unrelated	Paal	Piel	
1sg past	טיפסתי	נשקתי	נישקתי	התנשק
	TIPaSTI	NaShaKTI	NIShaKTI	HiTNaSheK
	"I climbed"	"I kissed/touched"	"I kissed"	"he kissed" (reciprocal)
Infinitive	לבחור	ללמוד	ללמד	התלמד
	LiVXOR	LiLMOD	LeLaMeD	HiTLaMeD
	"to choose"	"to learn"	"to teach"	"he did an internship"

Note: Examples include both Hebrew orthographic forms and their phonological form in Latin script (upper case letters represent letters that are present in the Hebrew orthographic form, in which vowels are typically omitted).

Hitpael verb forms in the 3sg past, a form that does not display inflectional affixes (i.e., it is constituted only by root+pattern). Each target word was paired with three types of primes: (a) a prime belonging to the Paal class, based on the same verbal root as the target, (b) a prime belonging to the Piel class, also based on the same root, and (c) an unrelated prime. Half (21) of the targets were preceded by primes presented in the 1sg past form (1sg past condition), and the other half of the targets were preceded by primes presented in the infinitive form (infinitive condition). Neither primes nor targets were homographic with any other form in Hebrew. A list of all experimental primes and targets employed in this study is presented in the Supplemental Material.

Table 3 displays means and standard deviations of different stimuli properties, for each experimental condition. Frequency values were based on a corpus of over 130 million tokens (Itai & Wintner, 2008) and are expressed in the Zipf scale (i.e., log10 of frequency per billion; van Heuven, Mandera, Keuleers, & Brysbaert, 2014). Semantic relatedness scores for each prime–target pair were obtained in a pretest conducted with 26 native speakers of Hebrew, who were asked to rate semantic relations between infinitive forms on a scale from 1 ("Not at all related") to 7 ("Very related").

As can be seen in Table 3, targets in the 1sg past and infinitive conditions were very closely matched in their mean values of lemma frequency and number of letters. Within each condition, Paal and Piel primes were also closely matched in mean lemma frequency and in their semantic relatedness to Hitpael verbs. Unrelated primes were based on different verbal roots (i.e., morphologically unrelated to the target) and had no orthographic, phonological, or semantic overlap with their corresponding target forms. Half of the unrelated primes belonged to the Paal binyan, and half belonged to the Piel binyan. Unrelated primes were matched in mean lemma frequency to both Paal and Piel primes, in both the 1sg past and the infinitive conditions.

One reviewer expressed the concern that spelling in Hebrew is often inconsistent, particularly with regard to the omission and redundant insertion of vowel letters (see, e.g., Ravid & Kubi, 2003). As mentioned above, the orthographic forms in the different conditions differed in vowel letters (see Table 2), and this may conceivably have processing consequences. In particular, forms that are potentially subject to inconsistent spelling (i.e., forms in the Paal 1sg past and the Piel infinitive conditions, in which vowels are absent in non-pointed script) may take more time to process, perhaps reducing priming effects. In order to ensure that the particular materials that we have employed are spelled in a consistent way by adult speakers, we have conducted a spelling experiment with 20 native Hebrew speakers. All prime words of the Paal and Piel conditions were included in this experiment. Prime words were divided into two lists, so that Piel and Paal verbs with the same root would not be presented to the same participant. Words were presented auditorily, and participants were asked to type every word. In 96.43% of the responses, spelling of Paal and Piel primes was accurate. Vowel omissions (e.g., HPXTI instead of HIPXTI after hearing the word /hipaxti/) occurred in only 0.83% of the responses (7 responses), and there were no vowel insertions. From these results, we conclude that the prime words used in the present masked priming experiment are spelled in a stable way by native speakers. Therefore, any

Table 3. Means of stimulus properties, for all conditions.

Condition	Lemma frequency (Zipf)	Semantic relatedness (1–7)	Length (in letters)
1sg past			
Unrelated	4.27 (0.74)	1.40 (0.33)	5.52 (0.51)
Paal	4.21 (0.97)	3.78 (0.78)	5.05 (0.22)
Piel	4.37 (0.64)	3.97 (0.84)	6.05 (0.21)
Target	3.31 (0.83)		5.00 (0.00)
Infinitive			
Unrelated	4.43 (0.58)	1.42 (0.25)	4.57 (0.51)
Paal	4.33 (0.61)	3.57 (0.94)	5.00 (0.00)
Piel	4.52 (0.70)	3.78 (0.80)	4.00 (0.00)
Target	3.29 (0.92)		5.00 (0.00)

Note: Standard deviations in parentheses.

potential reduction of priming effects in the Paal 1sg past and Piel infinitive conditions cannot plausibly be attributed to differences in the consistency of their spelling.

A set of 294 filler prime-target pairs were also included in the experiment (126 word-word pairs and 168 word-nonword pairs). Therefore, every participant saw 336 targets, half of them words and half pseudowords. Critical prime–target pairs were distributed over three experimental lists, so that each target appeared only once in each list. Participants were randomly assigned to one of the three lists, such that each list was presented to 10 participants.

Procedure

Participants were tested individually in a quiet room. They were asked to perform a lexical decision task on visual targets, as quickly and accurately as possible. Specifically, they were instructed to press a gamepad button (labelled "Yes"), using their dominant hand, when they recognized an existing word in Hebrew, and to press another button (labelled "No"), using their non-dominant hand, when they were presented with pseudowords. The DMDX software (Forster & Forster, 2003) was used for stimulus presentation and data collection. The experiment started with a practice phase including 12 trials (6 words and 6 pseudowords). The 336 experimental trials were then presented in a pseudo-randomized order, with three breaks provided during the experiment. Every trial consisted of the following events, in immediate succession: a fixation cross (500 ms), a blank screen (500 ms), a row of hash marks (500 ms), a prime word (50 ms), and the target (presented until a response was made, up to a timeout of 2000 ms). Therefore, the stimulus onset asynchrony (SOA) between prime and target was 50 ms. Response times (RTs) were measured from the onset of target presentation. Primes and targets were presented in Arial font, primes in size 20 and targets in size 24. After the experiment, participants were asked a set of questions that probed for awareness of prime words. The whole session lasted approximately 30 minutes.

Data analysis

Two items from the 1sg past condition were removed from subsequent analyses due to very low accuracy (below 50%): *hidama* "was similar" and *hishtamer* "was preserved". All other items had accuracy rates of at least 80%. No participants were excluded. Incorrect responses (4.0%) and timeouts (0.4%) were removed from the dataset. In order to reduce the influence of outliers, extremely slow RTs (above 1500 ms) were discarded (1.3% of the remaining data). Finally, the distribution of RTs was normalized by applying a reciprocal transformation (i.e., −1000/RT; Baayen & Milin, 2010).

Reciprocal RTs were analysed using mixed-effects linear regression, with crossed random effects for participants and items. The following fixed predictors were included: (a) prime type (unrelated, Paal, Piel), (b) form type (1sg past, infinitive), (c) the prime type by form type interaction, and (d) trial (the position of each item in the experiment, centred). The factors prime type and form type were assigned treatment contrasts. Therefore, model estimates reflected comparisons against reference levels, and the statistical comparisons of interest were obtained by relevelling one or both factors and refitting the model.

In order to reduce the probability of Type I errors without sacrificing statistical power, we followed the recommendation of Matuschek, Kliegl, Vasishth, Baayen, and Bates (2015) and included random slopes if they improved model fit (as measured by Akaike information criterion, AIC). All possible random structures of prime type, form type, and their interaction were assessed. The best model (i.e., the one with the lowest AIC) contained no random slopes and is reported below.

Results

Table 4 displays mean RTs, standard errors (*SE*s), and accuracy rates in all conditions. Means and *SE*s were calculated from reciprocal RTs and were back-transformed. Accuracy rates were very high and were comparable across conditions. Therefore, they were not further analysed.

The results of the mixed-effects regression analysis are presented in Table 5. The two item sets were examined separately by changing the reference level of the form type variable. First, the effect of prime type on RTs was examined for the set of 1sg past targets, by comparing Paal and Piel primes against the unrelated baseline. The results show that the previous presentation of morphologically related Paal forms did not facilitate target recognition, as they elicited comparable RTs to those for primes that had no morphological relation to the target. In contrast, RTs were significantly faster after the presentation of Piel forms than after unrelated primes. Secondly, the effect of prime type on RTs was examined for the infinitive set, by relevelling the form type factor. As was the case in the 1sg past set of items, Paal primes presented in the infinitive also failed to facilitate lexical decision responses, but RTs after Piel primes were significantly faster than after unrelated primes. Consistent with this pattern, there were no interactions between form type and the levels of prime type—that is, magnitudes of priming elicited by Paal and Piel verbs were not modulated by whether they were presented as infinitives or as 1sg forms.

Because no interactions were present, Paal and Piel priming was also assessed across all items in both the infinitive and 1sg past conditions (by assigning "main effect" contrasts to Form Type, i.e., converting the factor to a numeric format and centring it). This model also showed significantly shorter RTs after Piel primes than after unrelated primes ($b = -0.0611$, $t = -3.14$, $p = .002$), but

Table 4. Back-transformed means and accuracy rates for each condition.

Form type	Unrelated		Paal		Piel	
	RT (ms)	Acc. (%)	RT (ms)	Acc. (%)	RT (ms)	Acc. (%)
1sg past	634 (10.94)	94	629 (10.34)	97	609 (9.46)	97
Infinitive	641 (10.08)	94	639 (10.91)	94	620 (10.81)	97

Note: Standard errors in parentheses. 1sg past = first-person singular past form; RT = reaction time; Acc. = accuracy.

Table 5. Results from a mixed-effects regression on reciprocal RTs, with infinitive and 1sg past as reference levels.

Fixed effect	Estimate (*b*)	*SE*	*t*	*p*
Reference for form type: 1sg past				
Intercept	−1.5696	0.0536	−29.28	<.001
Prime type: Paal (vs. unrelated, 1sg past)	−0.0167	0.0281	−0.59	.554
Prime type: Piel (vs. unrelated, 1sg past)	−0.0634	0.0283	−2.24	.024*
Form type (in unrelated)	0.0220	0.0509	0.43	.666
Prime type: Paal × Form Type	0.0190	0.0391	0.49	.626
Prime type: Piel × Form Type	0.0045	0.0390	0.12	.908
Trial (centred)	−0.0002	<0.0001	−2.10	.036*
Reference for form type: Infinitive				
Intercept	−1.5475	0.0524	−29.53	<.001
Prime type: Paal (vs. unrelated, infinitive)	0.0023	0.0271	0.08	.932
Prime type: Piel (vs. unrelated, infinitive)	−0.0590	0.0269	−2.20	.028*

Note: Redundant coefficients for the infinitive reference level are not shown (i.e., form type, Prime Type × Form Type, and trial), as these are identical to the ones with 1sg past reference. 1sg past = first-person singular past form; RT = reaction time.
*$p < .05$.

no priming effect from Paal verbs ($b = -0.0068$, $t = -0.35$, $p = .728$). Furthermore, Piel primes elicited significantly faster RTs than Paal primes ($b = -0.0543$, $t = -2.80$, $p = .006$)—that is, larger root priming was obtained from verbs belonging to the Piel binyan than from verbs of the Paal binyan.

Discussion

The main finding of the present study is that forms of Hebrew verbs belonging to the Paal and Piel verb classes (or *binyanim*) produce different masked priming effects on the recognition of verbs that share the same root. A clear dissociation between the two classes was obtained: The presentation of Piel verbs produced robust priming effects, while Paal verbs did not facilitate target recognition. Importantly, this pattern of results was replicated in two different sets of primes and targets, one for which all primes were presented in the 1sg past form and another for which all primes were presented in the infinitive form.

We interpret these results as evidence that the early stages of visual lexical access in Hebrew are modulated by abstract morphological information—namely, binyanim membership. Accounts that instead attribute morphological effects to prime–target overlap in form and meaning (e.g., Gonnerman et al., 2007), or to the consistency of mappings between orthographic and semantic representations across the language (Plaut & Gonnerman, 2000), cannot easily explain our results, for several reasons. First, Paal and Piel primes were closely matched with respect to their semantic transparency to the Hitpael targets. Secondly, Paal and Piel primes were also very closely matched in their orthographic overlap with the targets, such that exactly the same three letters in the target (the root) were activated by all morphologically related primes. A small orthographic difference between Paal and Piel primes was indeed present within each item set: Piel primes presented in the 1sg past contained an additional letter that was not present in the target, but this difference was reversed for primes presented in the infinitive (in which Paal primes contained an additional letter); nevertheless, exactly the same priming pattern was obtained in both item sets. Thirdly, the masked priming paradigm typically produces reduced semantic effects at short SOAs, as well as small word-to-word orthographic effects (and especially so in Hebrew; Velan & Frost, 2007, 2009). Finally, the Paal and Piel classes are, as a whole, remarkably similar in a range of morphological and non-morphological properties: (a) They form structured stems, constituted by vowel patterns and productive consonantal roots; (b) their vowel pattern morphemes do not encode specific syntactic or semantic information; and (c) they have comparable type frequencies in the language. Therefore, we conclude that the priming pattern

that we obtained cannot be explained by differences in formal or semantic overlap or in the consistency and strength of form-to-meaning mappings across the language.

It is true, however, that in certain verbs the second root consonant of the Hitpael targets is phonologically more similar to its counterpart in Piel, than in Paal. In particular, certain root consonants in the second position (*K*, *B*, *P*) surface as stops in Piel and Hitpael verbs (e.g., איבדתי / i**b**adti/ → התאבד /hit?a**b**ed/), but may be fricatives in Paal verbs (e.g., אבדתי /a**v**adti/ → התאבד /hit?a**b**ed/). Because this change is not salient in Modern Hebrew (Adam, 2002), is restricted to these three letters, and is not accompanied by any orthographic changes, it is unlikely to play a role in morphological priming effects. Nevertheless, an additional analysis was carried out, in which we excluded the four items for which the second root consonant could be considered phonologically more similar between Piel primes and Hitpael targets (3 items from the 1sg past condition and 1 from the infinitive condition). This analysis produced exactly the same pattern of results—that is, a significant priming effect for Piel ($b=-0.0671$, $t=-3.20$), but not for Paal primes ($b=-0.0180$, $t=-0.85$), as well as greater priming for Piel than for Paal ($b=-0.0491$, $t=-2.34$). Furthermore, even if this alternation of the second root consonant was conceived of as an abstract underlying phonological feature that is present in all Piel and Hitpael verbs (rather than in only those with *K*, *B*, and *P* in the second root position), it is hard to see how this would explain the full pattern of our results. This additional phonological feature would amount to a very small difference in overlap, especially when compared to the large orthographic and morphological overlap that exists for *both* Paal and Piel primes. Nevertheless, despite the large overlap between Paal and Hitpael forms, a clear dissociation between binyanim was obtained, such that only Piel–but not Paal–forms elicited a robust root priming effect.

In contrast to distributed accounts, which invoke the convergence of orthographic and semantic codes to explain morphological priming effects, decompositional accounts propose that word recognition in Semitic languages is achieved via rapid decomposition into morphological constituents, such that the consonants of the root are the targets of lexical search (Boudelaa & Marslen-Wilson, 2015; Velan & Frost, 2011). These proposals also fail to explain the full pattern of results in the present study, because they predict that root extraction underlies the recognition of all structured forms in Hebrew (Deutsch et al., 1998). In contrast, our results demonstrate that morpho-lexical representation in Hebrew includes entries (in our case, Paal verb stems) for which lexical access does not involve down-to-the-root parsing. While it is true that simple "non-Semitic" Hebrew words (Velan & Frost, 2011) and irregularly inflected nouns (Vaknin-Nussbaum & Shimron, 2011) are also thought to be accessed via their stems or full forms (rather than by decomposition), our study is the first to identify a word class that displays a prototypical root and pattern Semitic structure, but fails to produce the familiar root priming effect.

Common to both morphological (rule-based) and non-morphological (distributed) accounts of the Semitic mental lexicon is the notion that the pervasive internal structure of Semitic stems shapes the language processing system (Bick et al., 2011; Boudelaa & Marslen-Wilson, 2011, 2015; Plaut & Gonnerman, 2000). The results from the current study suggest that such proposals might benefit from qualification. Specifically, our study has revealed similarities between word recognition in Semitic and in Indo-European languages, with respect to the distinction between lexical storage and grammatical computation. The striking difference between Paal and Piel verb classes is that despite their comparable frequencies, the Paal binyan constitutes a closed class, whereas the Piel binyan is an open class that can be extended to new verbs. One straightforward way of explaining how distinct priming effects coincide with productivity differences is by postulating that Piel, but not Paal, stems are rule based. Rules are operations over variables (Marcus, 2001)—that is, they readily apply to whole categories (e.g., "verbal root"). At the same time, rules are combinatorial operations, which means that they can be employed to decompose stems into morphological constituents. If the processing of Paal verbs is not mediated by a "Paal rule", then their recognition will necessarily depend on access to whole (undecomposed) stems. As such, under this perspective, the "Semitic mental lexicon" is not fully decompositional but, instead, shows a division of labour between structured and undecomposed stems. This distinction between stored entries and combinatorial operations is also present in the processing of complex forms and stems in a range of Indo-European languages (e.g., Sonnenstuhl et al., 1999; Veríssimo & Clahsen, 2009) and has been argued to be a fundamental feature of language (e.g., Clahsen, 1999; Pinker, 1999; Pinker & Ullman, 2002).

It is true that the morphology of Semitic languages has "special characteristics" (Frost, 2006, p. 440), in that morphological units (roots and patterns) surface in a discontinuous way. This means that rules of stem formation must be able to manipulate representations that can be non-linearly combined—for example, verbal patterns that contain "open slots" for root consonants. In addition, mechanisms of lexical access in Hebrew need to be flexible enough to extract constituents that are interleaved, rather than being dependent on the concatenation of surface strings or on the identification of stand-alone semantic units. Nonetheless, our results suggest that when it comes to the fundamental mechanisms that morphology depends on, Hebrew complex words show the same division of labour between storage and computation as that seen in many other languages. We conclude that there is no "Hebrew brain" or "English

brain" (Bick et al., 2011, p. 2280). Rather, in both languages, the processing system reflects the dual nature of the language faculty and makes use of the same universal architecture.

Notes

1. We use *C* to represent root consonants.
2. The studies mentioned here have employed overt priming paradigms, which (unlike the masked priming technique that is used in the present study) may be susceptible to strong effects of semantic relatedness. Nevertheless, all studies contrasted verb classes that were perfectly matched with regard to semantic transparency, indicating a morphological (rather than semantic) source for the contrast between productive and non-productive operations.
3. In a small number of roots ($n=4$), however, the *phonological* similarity between Piel and Hitpael verbs is slightly larger than is normally the case, because their patterns show a predictable phonemic alternation between stops and fricatives. We return to this issue in the Discussion section and present an analysis without the items in which this phonemic change occurs.

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Supplemental material

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