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Decomposing Morphologically Complex Words in a Nonlinear Morphology

Ram Frost and Avital Deutsch
Hebrew University of Jerusalem

Kenneth I. Forster
University of Arizona

Most Hebrew words are composed of 2 intertwined morphemes: a triconsonantal root and a phonological word pattern. Previous research with conjugated verb forms has shown consistent priming from the verbal patterns, suggesting that verbal forms are automatically parsed by native speakers into their morphemic constituents. The authors investigated the decomposition process, focusing on the structural properties of verbal forms that are perceived and extracted during word recognition. The manipulations consisted of using verbal forms derived from "weak" roots that have one consonant missing in some of the forms. The results demonstrated that if 1 consonant is missing, the parsing system collapses, and there is no evidence for morphological priming. In contrast, when a random consonant is inserted into the weak form, the verbal-pattern priming re-emerges. This outcome suggests that the constraint imposed on the decomposition process is primarily structural and abstract. Moreover, the all-or-none pattern of results is characteristic of rule-based behavior and not of simple correlational systems.

The role of morphological units in lexical access is a fundamental issue in models of word recognition. Although some investigators suggest that the primary unit of representation and analysis of polymorphemic words corresponds to the surface word (e.g., Butterworth, 1983; Henderson, Wallis, & Knight, 1984), current opinion is moving more strongly toward some form of sublexical morphemic account. Earlier models of word recognition (e.g., Taft, 1981; Taft & Forster, 1975) argued for a model of morphemic decomposition, in which all polymorphemic words are mandatorily decomposed into their morphemic components and initial access occurs by means of the base form. Recent studies have taken a more nuanced approach, suggesting that analysis and decomposition occurs for some words but not for others (e.g., Baayen, 1991; Burani & Laudanna, 1992; Caramazza, Laudanna, & Romani, 1988; Frauenfelder & Schreuder, 1991; Frost, Forster, & Deutsch, 1997; Laudanna, Burani, & Cermele, 1994; Marslen-Wilson, Tyler, Waksler, & Older, 1994; Schreuder & Baayen, 1995; Taft, 1994). A decompositional theory of morphological processing needs, therefore, to provide adequate answers for two important questions. First, what parameters determine whether a specific morphological unit will serve as an access representation, thereby mediating lexical access? Second, what parameters govern the on-line process of lexical decomposition that allows these morphemic units to be recognized by the cognitive system?

Our previous work on Hebrew morphology (Deutsch, Frost, & Forster, 1998; Frost et al., 1997) has focused mainly on the first question. In Hebrew, as in other Semitic languages, most words can be decomposed into two abstract morphemes: the root and the word pattern.[1] Roots usually consist of three consonants, whereas word patterns can be either a sequence of vowels or a sequence consisting of both vowels and consonants. These morphemes are not appended to one another linearly, as in languages with a concatenated morphological structure, such as English or Italian. Rather, the consonants of the root are intertwined with the phonemes (and, therefore, the corresponding letters) of the word pattern. Roots and word patterns are abstract structures, because only their joint combination results in specific word forms with specific meanings. These meanings cannot necessarily be predicted by analyzing the two morphemes independently from one another. For example, the Hebrew noun *MIKDAMA* (meaning *prepayment*) consists of the combination of the root morpheme K.D.M (conveys the meaning of advancing) with the word pattern MI-A-A (which conveys the grammatical form of feminine nouns. The dashed lines stand for the places where the root

Ram Frost, Department of Psychology, Hebrew University of Jerusalem, Jerusalem, Israel; Avital Deutsch, School of Education, Hebrew University of Jerusalem, Jerusalem, Israel; Kenneth I. Forster, Department of Psychology, University of Arizona.

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Correspondence concerning this article should be addressed to Ram Frost, Department of Psychology, Hebrew University of Jerusalem, Jerusalem, 91905 Israel, or to Avital Deutsch, School of Education, Hebrew University of Jerusalem, Jerusalem, 91905 Israel.

[1] There are also additional derivational morphemes in Hebrew. These morphemes are attached to the stem form (which is usually a complex form of a root and a word pattern) linearly, as prefixes or, more frequently, as suffixes. The present study focuses on the decomposition of the nonconcatenative structure of roots and word patterns.

consonants are to be inserted into the word pattern). The same principle also applies to the verbal system. For example, the word *HIKDIM* (meaning "he was early") is formed by the same root K.D.M interwoven with the word pattern HI--I- (which conveys an active verbal form).

These two basic morphemic units in Hebrew (the root and the word pattern) differ in some of their linguistic characteristics. The root carries the core meaning of the words, whereas the word pattern provides mainly grammatical information such as definition of word class or a verb's transitivity. Although the specific meaning of words is defined by the combination of the root with the word pattern, the semantic specificity of word patterns is often vague and inconsistent, especially in the nominal system. There are many more nominal patterns (more than 100) than verbal patterns (only 7: 3 active patterns, 3 passive patterns, and 1 reflexive pattern). Because any verb in Hebrew must be derived using one of the existing 7 patterns, the same group of 7 members repeats itself in the various conjugated verbs, making the phonological form of each pattern very salient. In addition, within the group of 7 verbal patterns one can identify an internal system of mutual connections based on relatively consistent semantic relations (Ben-Asher, 1971). Thus, in contrast to the nominal system, the actual meaning of a verbal form can often be predicted by analyzing its two morphological components. The derivational system of verbal forms in Hebrew may, therefore, be characterized as a system with fairly high distributional properties, one whose constituents are relatively phonologically as well as semantically transparent. Because in the present study we focus on the verbal system, we next briefly describe the main characteristics of the 7 verbal patterns (for a more detailed description, see Deutsch et al., 1998).

The Verbal Patterns

Active Patterns

There are three active patterns.[2] The first pattern is -A-A-, such as *KAPATS* (meaning "he jumped"; the sequence *TS* stands for the alveolar fricative voiced phone). This pattern is characterized morphologically by the absence of any consonantal affixes in the basic form. The semantic meaning denoted by this pattern is usually of an active action or a stative verb. The second pattern is -I--E-, such as *KIPETS* ("he was jumping"). This pattern is morphologically characterized by the doubling of the second consonant of the root.[3] The common semantic characteristic ascribed to the -I--E- pattern is of a factitive action and sometimes of an intense, repetitive action. The third pattern is HI--I-, such as *HIKPITS* ("he caused something to jump"). This pattern is morphologically characterized by the prefix *H*. Its usual semantic characteristic is to denote a causative action of verbs in the -A-A- pattern.

Passive Patterns

The most typical passive patterns are -U--A- and HU--A-. These two passive patterns correspond to the active forms of -I--E- and HI--I-, respectively (e.g., *HIKPITS,* meaning "caused something to jump," and *HUKPATS,* meaning "was made to jump"). Another passive word pattern is NI--A- (such as *NISBAR,* meaning "got broken"), which is morphologically distinguished by the prefix *N*. However, NI--A- may denote active actions as well.

Reflexive Pattern

There is only one typical reflexive pattern in modern Hebrew, the HIT-A--E- pattern (such as in the word *HITXADES,* meaning "he renewed himself"). Its unique morphological characteristic is the prefix *HIT.* The HIT-A--E- pattern may also convey a reciprocal action (such as in the word *HITNASEK,* meaning simultaneously "to kiss" and "to be kissed").

In a series of recent studies, both masked priming and crossmodal priming have been used to examine the role of roots and word patterns in Hebrew lexical organization and lexical access (Deutsch et al., 1998; Frost et al., 1997; Frost, Deutsch, Gilboa, Tannenbaum, & Marslen-Wilson, in press). In a first set of studies looking at the nominal system with masked priming, Frost et al. (1997) found that when primes and targets shared an identical word pattern, lexical decisions and naming of targets were not facilitated. In contrast, root primes facilitated both lexical decision and the naming of target words that were derived from these roots. This suggested that Hebrew roots are lexical units and govern lexical access, whereas nominal word patterns are not. In contrast, however, in a further series of experiments within the verbal system, clear evidence was found for a facilitatory priming effect induced by the word patterns (as well as by roots; Deutsch et al., 1998). This discrepancy between the nominal and verbal systems with respect to the word pattern priming effect was so striking that Frost et al. (in press) replicated the above experiments while using a cross-modal presentation. In the crossmodal task, the use of spoken primes ensured full processing and awareness of the phonological structure of the word pattern. Similar to our masked priming experiments, Frost et al. (in press) found significant word pattern priming for verbal forms, but not for nominal forms. This suggests that Hebrew words are mandatorily decomposed into roots and word patterns during lexical access and that verbal patterns have a much more distinct status as cognitive units than do noun patterns, probably because of their distributional properties and their semantic transparency.

Our goal in the present article is to examine the actual process of morphological decomposition while focusing on the nature of the repeated units that the system learns to recognize and extract from the morphological complex structure. We were mainly interested in the following

[2] The word patterns are named according to the morphological structure of the base form; that is, the unmarked inflected form of the singular, third-person point of view in the past tense, on which all inflections for person, number, and tense are performed.

[3] The two dashed lines between the two vowels in the pattern -I--E- represent gemination of the second consonant of the root. In pointed print this is indicated by a dot inserted in the middle of the second root consonant.

question: Is morphological decomposition a process by which the system merely picks up statistical regularities between any orthographic clusters and semantic properties, regardless of their linguistic definition, or do the decomposed units relate to a unique level of morphological representation? Furthermore, if these units are represented at a morphological level, what is the interplay between abstract structural parameters versus specific phonological components during the decomposition process? It should be emphasized that the word pattern in Hebrew plays a central role in determining the phonological structure of the entire word. It preserves the prosody, stress, vowel sequence, and some consonants of the word but does not consist of a unified pronounceable phonological sequential unit. Thus, any model of morphological decomposition in Hebrew needs to provide an adequate description of how exactly the native speaker parses an input word into its noncontiguous morphemic constituents and must explain the role of the morphological level of representation in the process of decomposing a complex word into its structural components.

To investigate this decomposition process, we focused in this study on the structural properties of the verbal forms. Our investigation was concerned with the possible parsing strategies adopted by the cognitive system while processing conjugated verbs. We focused on verbal forms, because our previous investigation revealed that, for verbs only, both the root and the word pattern morpheme have a role in lexical access. Thus, our aim was to examine how the phonemes (or letters) of a given verb are decomposed into those belonging to the pattern and those belonging to the root and whether there are some salient behavioral properties that characterize this parsing mechanism. Our experimental manipulation throughout the present study consisted of using a special subset of verbal forms that pose a genuine difficulty in parsing. These forms are labeled in Hebrew *weak roots.*

"Weak Roots"

As in other Semitic languages, most Hebrew roots are composed of three consonants, although there are some examples of roots with four consonants. The three-consonant structure is especially prominent in the verbal system, in which a consonantal skeleton of at least three components is mandatory for the conjugation of any verbal form (Blau, 1971). However, there is one group of roots in Hebrew, called the *weak roots,* in which the complete three-consonantal structure is not kept in some of the conjugations. These belong to two main classes: *defective roots,* characterized by an omission of one of the consonants in certain conjugations, and *mute roots,* in which one consonant, although present, is not pronounced because of some linguistic processes (such as sound shifting, analogies in conjugation, and phonetic assimilation) that occurred in Hebrew through history. Although the phenomenon of the weak root seems to be a peculiar case anchored in phonetic and historical linguistic processes, we should emphasize that there are many weak roots in Hebrew (about 10% of the roots), and many of them form common, frequently used verbs.

In the "defective" roots (see Example 2 of Table 1) the weak radical is assimilated into the following radical. This assimilation is reflected by the gemination of the following consonant and is orthographically marked by a diacritical point inserted into the geminate consonant. The phonetic expression of the gemination is of an emphasized articulation. However, the gemination mark is part of the diacritical marks system used to denote the vowels (see Frost & Bentin, 1992, for a detailed description). Because in most Hebrew reading material the diacritical points are not represented, the reader is usually not aware of this gemination. Moreover, in modern Hebrew only three consonants have preserved the phonetic expression of the gemination. Thus, without specific training in linguistics the existence of a defective root radical in the form is far from being obvious to any native speaker, and the gemination by itself does not reveal the identity of the consonant that was assimilated.

In the "mute" roots, one of the radicals becomes a quiescent letter in some of the root conjugations as it is

Table 1
Examples of One Complete Root and Some of the Different Types of Weak Roots Conjugated in the Fifth Verbal Pattern, HI—I-, Masculine Third-Person Singular

Example	Root type	Phonetic transliteration of the verbal form	Orthographic transliteration	Meaning
1	Complete root s.p.k ס.פ.ק	/hispik/	hspyk הספיק	He was able to
2	First radical /n/, defective n.p.l נ.פ.ל	/hipil/	hpyl הפיל	He overthrew
3	Second radical /y/, mute q.y.m ק.ו.מ	/heqim/	Hqym הקים	He raised
4	First radical /y/, mute y.r.d י.ר.ד	/horid/	Hwryd הוריד	He took down

Note. Root letters are underlined.

written but not pronounced (Example 3 of Table 1).[4] The presence of the quiescent consonant creates a change in the syllabic structure of the pattern (e.g., from a consonant [C]/vowel [V]/C–CVC to a CV–CVC structure, as in the examples of Table 1). In some cases it may also entail some minor phonological variations, such as a change in one vowel of the verbal pattern (see Example 4 of Table 1). As a consequence of such changes, the speaker of the language often loses the cues that could be of help in identifying the mute consonant and, consequently, the exact identity of a root radical is unclear. The identification of the "missing" consonant is further impeded by the fact that weak roots may appear "weak" in some conjugations, whereas their complete form would appear in other conjugations. Table 1 illustrates the phonological changes of the verbal pattern HI--I- when conjugated with weak roots. It should be noted that although this verbal pattern goes through various phonological variations when conjugated with the various types of weak roots, it keeps its main morphological characteristic, such as the consonant /h/ at the beginning of the form. Thus, despite the fact that native speakers may find it hard to come up with the correct root phoneme that is "missing" in the form, there would be no argument as to the verbal pattern with which the verbal form is conjugated. Hence, from a purely linguistic perspective, the verbal patterns of weak-root and complete-root forms are treated and analyzed alike. Weak-root forms, however, present an interesting parsing problem to the native speaker, for if three consonants of the form are assigned to the root, there would be one missing for the verbal pattern, and if all the correct consonants are assigned to the verbal-pattern morpheme there would be only two consonants left for the root. This would violate the formal triconsonantal structural representation of Semitic roots.

We investigated whether such parsing complexity would have any effect on the decomposition of verbs as revealed by the priming from verbal patterns. Our previous investigation revealed robust and consistent priming effects when the primes and the targets were conjugated with the same verbal pattern (Deutsch et al., 1998). This outcome demonstrated that verbal forms are decomposed during word recognition and that verbal-pattern morphemes govern lexical access of verbal words. Our experiments, therefore, consisted of examining the verbal priming effect, as reflecting the decomposition process, when the primes and the targets were conjugated with the same verbal patterns but contained weak roots. If the parsing algorithm initially searches for an abstract three-consonantal structure that is characteristic of Semitic languages, weak-root forms will necessarily show severely reduced priming effects. If, on the other hand, the parsing system simply focuses on the orthographic or phonologic units that repeatedly recur in morphologically related words, then priming effects will show with weak-root forms as well.

General Method

As in our previous investigations of morphological processing, we conducted all of the experiments in the present study using the visual masked priming technique developed by Forster and Davis (1984). In masked priming, a forward pattern mask is presented immediately before the prime, and the temporal interval between the onset of the priming stimulus and the subsequent target stimulus is very brief (42 ms, in our experiments). Because the prime is presented briefly and is masked by a combination of forward and backward masking (the latter coming from the target), the prime itself is usually unavailable for report. Participants have no, or very little, direct conscious awareness of the prime. The advantage of this procedure for the present purposes is that participants' responses to the targets are unlikely to be influenced by strategic processes that rely on a conscious appreciation of the morphological relationship between the prime and the target. This reduces the possibility that any priming effect is due to the fact that participants consciously recognize that the prime and the target share a common morpheme (in the context of the present study, the verbal pattern). A further advantage of the masked priming technique is that masked priming has been shown to be highly sensitive to overlap at the level of form (e.g., Forster, Davis, Shoknecht, & Carter, 1987; Forster & Taft, 1994), but not of meaning. Although masked priming effects for associatively related pairs have been reported (e.g., Perea, Gotor, Rosa, & Algarebel, 1995; Sereno, 1991), previous studies in our laboratory did not find any facilitation due to purely semantic relations (Frost et al., 1997). This feature of masked priming is of special interest in the study of morphology, because it enables the monitoring of morphological effects that stem from form overlap rather than simple semantic relatedness.

Our working hypothesis using masked priming is that facilitation in this paradigm reflects a transfer effect; that is, priming results from the fact that the processing carried out on the prime is transferred across to the target. This transfer is made possible when the prime and target have overlapping representations. This assumption is based on several studies showing that priming can result from orthographic overlap (see Forster, 1987, for a review). However, in the case of morphological priming this account has to be extended, because the priming effect cannot be explained merely in terms of orthographic similarity. Because the morphological priming effect is measured by comparing performance in a morphologically related condition with an orthographic control condition that has the same degree of orthographic overlap with the targets, the priming effect indicates the additional contribution of the morphological component to simple orthographical effects (see also Forster et al., 1987; Grainger, Cole, & Segui, 1991). It is, therefore, necessary to assume that there are additional units that are shared between the prime and target and that these units are

[4] The origin of the mute-root phenomenon is that five consonants (or consonant letters) in Hebrew are in fact semivowels or glotal consonants. These consonants, for phonetic reasons, went through various processes of sound shifting and phonetic assimilation while conjugated as verbal form, because of the construction of analogies to regular consonants (for a more comprehensive description, see Blau, 1971).

activated whenever the prime or the target are recognized. We suggest that these lexical units are morphemic in nature. Because our model of morphological processing in Hebrew (Deutsch et al., 1998) suggests that the extracted morphemic units mediate the recognition of the target words, the source of the verbal-pattern priming effect is the activation (or location) of the verbal pattern of the target that is due to the brief exposure of the prime.

All of the present experiments also included an identity condition that provides an estimation of the maximal priming effect that could be obtained under the specific experimental condition. Another purpose of including the identity condition was to obtain a control procedure that would verify that the primes were processed and exerted their influence on the targets in spite of the brief exposure.

Experiment 1

In Experiment 1 we compared the priming effects of verbal patterns that are conjugated with complete roots with the priming obtained with the same patterns but conjugated with weak roots. Thus, the experiment comprised four conditions (note that in the following examples only the phonological form is depicted. Because in unpointed Hebrew some vowels are not represented in print, the orthographic structure may be different). In the complete-root–related condition, primes and targets were verbal forms derived from complete roots and conjugated with identical verbal patterns (e.g., *HISRIT–HISPIK,* both conjugated in the HI--I- pattern; prime root is *SRT*). The purpose of including this condition was to replicate the verbal-pattern priming effect obtained previously with complete roots and to provide a direct contrast to the priming effect obtained with weak roots within one experimental setting. In the weak-root–related condition the same target was primed by a verbal form having an identical pattern but conjugated with a weak root (e.g., *HIPIL–HISPIK,* again both conjugated in the HI--I- pattern, but now the defective root *NPL* has only two pronounced consonants in the conjugated form: the *P* and the *L*). Facilitation in these two related conditions was determined relative to control primes that shared the same number of letters with the target as the morphologically related primes, but not the verbal patterns (e.g., *HITPAREK–HISPIK*). The fourth condition involved identity priming: The same target was primed by itself.

Method

Participants. The participants were 64 undergraduate students at Hebrew University, all native speakers of Hebrew, who took part in the experiment for course credit or payment.

Stimuli and design. The stimuli consisted of 48 target words that were four or five letters long and contained two syllables with six phonemes. The target words were derived from the base forms (past, singular, masculine) of the verbal patterns: HI--I-, HU--A-, and NI--A-, because the weak radical is often omitted or becomes mute in these patterns. Each target word was paired with four primes to form the identity, related-complete root, related-weak root, and control conditions. Primes and targets overlapped by two or three letters across the four conditions, and the position of overlapping letters and phonemes in the related and the control conditions was always initial (given the patterns used) but could be also middle or final, with similar distributions in the related and the control conditions. An example of the stimuli used in the experiment is presented in Table 2.

Each target word and its prime were paired with target and prime nonwords composed of the same word patterns as above, but with nonexisting roots. As with the word targets, the nonwords too were divided into four experimental conditions mimicking the orthographic features of the words' conditions. The stimuli were divided into four lists. Each list contained 12 words and 12 nonwords in each of the four experimental conditions. The stimuli were rotated within the four conditions in each list in a Latin square design. Sixteen different participants were tested on each list, performing a lexical decision task. This procedure allowed each participant to provide data points in each condition within one of the experimental tasks while avoiding stimulus repetition effects.

As in our previous investigation of the verbal system, the stimuli were presented in unpointed Hebrew characters. However, all the verbal forms selected for the experiment were phonologically unambiguous and could be read as a meaningful word in only one way. We used unpointed script because this is the usual way that adults read Hebrew.

Procedure and apparatus. The experiment was conducted on an IBM Pentium computer. The software used for presentation of stimuli and for measuring the reaction times was the DMASTR display system developed by K. I. Forster and J. C. Forster at the University of Arizona. Each trial consisted of three visual events. The first was a forward mask consisting of a row of eight hash

Table 2
Examples of the Stimuli Used in Experiment 1 in the Identity, Related-Complete, Related-Weak, and Control Conditions

Experimental condition	Identity	Related–complete	Related–weak	Control
Forward mask	########	########	########	########
Prime	hspyk, /hispik/ (*he managed*) הספיק (s.p.k., ס.פ.ק)	hsryt, /hisrit/ (*he filmed*) הסריט (s.r.t., ס.ר.ט)	hpyl, /hipil/ (*he overthrew*) הפיל (n.p.l., נ.פ.ל)	htprk, /hitparek/ (*fell apart*) התפרק (p.r.k., פ.ר.ק)
Target	hspyk הספיק	hspyk הספיק	hspyk הספיק	hspyk הספיק

Note. Forward mask composed of hash marks.

marks, which appeared for 500 ms. The mask was immediately followed by the prime, with an exposure duration of 42 ms. The prime was in turn immediately followed by the target word, which remained on the screen until participants responded. All visual stimuli were centered in the viewing screen and were superimposed on the preceding stimuli. Although only one Hebrew square font was used, two versions of this font, which differed in their relative size, were included. Targets were always presented in the larger font (20% larger than the primes). This guaranteed complete visual masking of the primes by the targets and made the primes and the targets physically distinct stimuli.

Participants were instructed to make lexical decisions in regard to the targets by pressing a "yes" or a "no" key on the computer keyboard. Their responses were immediately followed by a feedback message, printed on the screen, that indicated (a) whether the response was correct and (b) the latency of the response. The initiation of each trial was controlled by the participants, who pressed the space bar when they were ready. No mention was made of the existence of the primes.

Results

We averaged the reaction times (RTs) for correct responses in the four experimental conditions across participants and across items. Within each participant, RTs that were outside a range of 2 *SD* from the participant's mean were curtailed. We minimized the effect of outliers by establishing cutoffs of 2 *SD* above and below the mean for each participant. Any RTs exceeding these cutoffs was replaced by the appropriate cutoff value. Trials on which an error occurred were discarded. This procedure was repeated in all of the following experiments. The effects of the identity and related primes were assessed relative to the control baseline. The results are presented in Table 3. Lexical decisions to targets were facilitated in the identity condition (54 ms) when the primes and the targets were the same word. The more interesting result, however, concerns lexical decisions to target words with morphologically related primes. In the complete-root condition a significant facilitation (17 ms) was obtained. In contrast, facilitation in the weak-root condition was very small and nonsignificant (6 ms).

Table 3
Reaction Times (RTs, in Milliseconds) and Percentage Errors for Lexical Decisions to Target Words and Nonwords in the Identity, Related-Complete–Root, Related-Weak–Root, and Control Conditions of Experiment 1

Identity		Related-complete root		Related-weak root		Control	
RT	%	RT	%	RT	%	RT	%
			Words				
544	3.6	581	6.8	592	6.8	598	6.1
			Nonwords				
630	7.8	632	5.6	632	6.8	637	8.2

Note. Identity priming: 54 ms; related-complete–root priming: 17 ms; related-weak–root priming: 6 ms.

We subjected the results to a two-way analysis of variance (ANOVA) in which the prime condition was one factor and the word list was the other. We used this procedure in all of the following experiments, but we report only the main effect of the prime because the list variable was introduced merely to extract any variance due to counterbalancing.

The prime-condition factor was significant in both participant and item analyses, $F1(3, 180) = 45.4$, $MSE = 832$, $p < .001$; $F2(3, 132) = 33.8$, $MSE = 866$, $p < .001$. Planned comparisons revealed that the difference between the related-complete root and the control conditions was significant for participants and for items, $F1(1, 60) = 11.3$, $MSE = 8{,}271$, $p < .001$; $F2(1, 44) = 7.0$, $MSE = 969$, $p < .01$. In contrast, the difference between the weak-root and control conditions was not significant for participants or for items, $F1(1, 60) = 1.4$, $MSE = 1{,}059$, $p < .24$; $F2(1, 44) = 1.4$, $MSE = 1{,}006$, $p < .25$. The error analysis revealed a significant prime condition factor, $F1(3, 180) = 3.1$, $MSE = 45$, $p < .03$; $F2(3, 132) = 3.24$, $MSE = 33$, $p < .02$. This was mainly due to the fact that participants made fewer errors in the identity condition. The number of errors in the both related conditions and the control condition did not differ significantly ($F1$ and $F2 < 1$). The prime condition had no effect on latencies ($F1$ and $F2 < 1$) or errors ($F1$ and $F2 < 1.6$) to nonwords. This is a consistent finding in our research, reflecting the lexical characteristic of the facilitation obtained with masked priming (see Frost et al., 1997, for a discussion).

Discussion

Experiment 1 yielded two interesting results: First, a strong facilitation effect was observed when primes shared the word pattern morpheme with the targets that had a complete root. This outcome constitutes a replication of initial findings reported both with masked priming (Deutsch et al., 1998) and with crossmodal priming (Frost et al., in press). Second, and more important, verbal-pattern priming was not obtained when the primes did not contain a complete root. Although in this condition primes and targets shared the same morphological patterns as in the complete-root condition, the weak root's missing consonant seems to have interfered somehow with the priming effect. One possible explanation for this result is that primes that do not contain three consonants cannot be decomposed into their morphemic constituents. If decomposition does not occur, verbal-pattern priming is indeed not expected. However, before accepting such a far-reaching conclusion, other accounts that focus on simple phonological similarities and dissimilarities between primes and targets should be investigated.

Experiment 2

The aim of Experiment 2 was to examine the verbal-pattern priming effect when both primes and targets consisted of weak-root forms. Because morphological priming emerges from a morphophonological structure that appears in both primes and targets, Experiment 2 provided an interesting contrast to Experiment 1. One possible shortcoming of our manipulation in Experiment 1 is that the primes containing a weak root were phonologically dissimilar to the targets containing a complete root. Thus, although both primes and targets were conjugated with the same morphological pattern, their surface forms differed. It is possible that this phonological dissimilarity caused the two phonological variations of the pattern to be perceived as two different patterns and therefore interfered somehow with the verbal-pattern priming effect, thereby reducing it significantly. Experiment 2 was designed to investigate this possibility.

We presented participants with primes and targets that had both a weak root and were both conjugated with the same verbal pattern (e.g., *HIGIS–HIPIL*). This resulted in prime–target pairs that were as phonologically similar as prime–target pairs conjugated with complete roots. If indeed some surface phonological differences interfered with the verbal-pattern priming effect in Experiment 1, then it should re-emerge in Experiment 2.

Method

Participants. The participants were 48 undergraduate students at Hebrew University, all native speakers of Hebrew, who took part in the experiment for course credit or payment. None of the participants had taken part in Experiment 1.

Stimuli and design. The stimuli consisted of 48 target words that were verbal forms conjugated with weak roots, derived from the base forms (past, singular, masculine) of the verbal patterns: HI--I-, HU--A-, and NI--A-. Targets were four to five letters long and contained two syllables with five phonemes. Each target word was paired with three primes to form the identity, related, and control conditions. Because both primes and targets in the related condition were derived from weak roots, phonological similarity between primes and targets was kept to a maximum, as with verbal-pattern priming with complete roots. Primes and targets overlapped by two or three letters across the four conditions, and the position of overlapping letters and phonemes in the related condition and the control condition was always initial (given the patterns used) but could be also middle or final, with similar distributions in the related condition and the control condition. An example of the stimuli used in the experiment is presented in Table 4.

Each target word and its prime were paired with target and prime nonwords composed of the same word patterns as above, but with nonexisting roots. As with the word targets, the nonwords too were divided into three experimental conditions mimicking the orthographic features of the words' conditions. The stimuli were divided into three lists. Each list contained 16 words and 16 nonwords in each of the three experimental conditions. The stimuli were rotated within the three conditions in each list in a Latin square design. Sixteen different participants were tested on each list, performing a lexical decision task.

Procedure and apparatus. The procedure and apparatus were identical to those in Experiment 1.

Results

We averaged the RTs for correct responses in the three experimental conditions across participants and across items. The results are presented in Table 5. Lexical decisions to targets were facilitated in the identity condition (42 ms) when the primes and the targets were the same word. The interesting result, however, is that, similar to Experiment 1, there was a very small and nonsignificant priming effect in the related condition (5 ms).

We subjected the results to a two-way ANOVA in which the prime condition was one factor and the word list was the other. The prime-condition factor was significant in both participant and item analyses, $F1(2, 90) = 30.6$, $MSE = 828$, $p < .001$; $F2(2, 90) = 24.0$, $MSE = 1{,}147$, $p < .001$, but this was due only to the faster latencies in the identity condition. Planned comparisons revealed that the difference between the related condition and the control condition was not significant for participants or for items ($F1$ and $F2 < 1$). The error analysis revealed a significant prime condition factor, $F1(2, 90) = 7.2$, $MSE = 42$, $p < .001$. This was mainly due to the fact that participants made fewer errors in the identity condition. The number of errors in the related condition and the control condition did not differ significantly ($F1$ and $F2 < 1$). The prime condition had no effect on latencies, $F1(2, 90) = 2.5$, $MSE = 588$, $p < .09$, and $F2 = 1.0$, or errors ($F1$ and $F2 < 1$) to nonwords.

Discussion

The inability to obtain verbal-pattern facilitation when both primes and targets have a weak root suggests that

Table 4
Examples of the Stimuli Used in Experiment 2 in the Identity, Related, and Control Conditions

Experimental condition	Identity	Related	Control
Forward mask	########	########	########
Prime	hpyl, /hipil/ (*he overthrew*) הפיל (n.p.l., נ.פ.ל)	hgyʃ[a] /higiʃ/ (*he served*) הגיש (n.g.ʃ., נ.ג.ש)	nkpl, /nikpal/ (*was doubled*) נכפל (k.p.l., כ.פ.ל)
Target	hpyl הפיל	hpyl הפיל	hpyl הפיל

Note. Forward mask composed of hash marks.
[a]The character "ʃ" stands for the palato-alveolar fricative phone.

Table 5
Reaction Times (RTs, in Milliseconds) and Percentage Errors for Lexical Decisions to Target Words and Nonwords in the Identity, Related, and Control Conditions of Experiment 2

Condition	Words	Nonwords
Identity		
RT	567	640
% Errors	5.7	11.0
Related		
RT	604	651
% Errors	9.9	11.6
Control		
RT	609	648
% Errors	10.2	11.6

Note. Both primes and targets were composed of weak roots. Identity priming: 42 ms; related-weak–root priming: 5 ms.

phonological similarity in itself is not a sufficient condition for word pattern priming. This conclusion concurs with previous findings using cross modal presentation, which showed that simple phonological overlap does not account for the morphological effects in Hebrew (Frost et al., in press). Experiment 2 thus clearly demonstrates that phonological dissimilarity was not the source of the difference between complete-root primes and weak-root primes in Experiment 1. Even when primes and targets have the same phonological structure, priming does not occur if one consonant is missing in the verbal form. This outcome leads us to entertain the possibility that verb forms with weak roots are not decomposed into their constituent morphemes or, alternatively, that this decomposition process is too slow to allow the primes to exert their influence on accessing the targets. Note that our working hypothesis is that masked priming reflects a transfer effect, that is, the result of processing carried out on the prime is transferred across to the target (see Forster, 1987, and Frost et al., 1997, for a discussion). This transfer, however, is not possible if the processing of the prime is too slow, given the close temporal proximity of the target. Experiment 3 was designed to investigate this possibility.

Experiment 3

In Experiment 3 we simply reversed the order of prime–target presentation so that complete-root verbal forms primed missing-root target forms. Now our participants were presented with priming stimuli that had three consonantal roots in the verbal form. This experimental condition normally reveals verbal-pattern priming, as shown in the complete-root condition of Experiment 1. If our inability to obtain verbal-pattern priming so far was due to a slow decomposition of the primes derived from weak roots, then complete-root primes should restore the missing priming effect. This is because the fast decomposition of the primes would facilitate the recognition of the weak-root targets, which share the same verbal patterns as the primes. One may even expect greater priming effects in this condition, because the successful decomposition of the complete-root prime may accelerate the slow decomposition of the weak-root target. If, on the other hand, verbal forms that miss one root consonant are not morphologically decomposed, the fast decomposition of the primes would not affect the recognition of the nondecomposable targets.

Method

Participants. The participants were 48 undergraduate students at Hebrew University, all native speakers of Hebrew, who participated in the experiment in exchange for course credit or payment. None of the participants had taken part in the previous experiments.

Stimuli and design. The stimuli consisted of the 48 prime–target pairs that were used in the related-missing–root condition of Experiment 1, but their order of presentation was reversed; the primes were the complete-root forms, and the targets were the weak-root forms. The design included again three experimental conditions: identity, related, and control. Similarly, the stimuli were divided into three lists, each containing 16 words and 16 nonwords in each of the three experimental conditions. The stimuli were rotated within the three conditions in each list in a Latin square design, and 16 different participants were tested on each list, performing a lexical decision task. The procedure and apparatus were identical to the previous experiment. An example of the stimuli used in the experiment is presented in Table 6.

Results and Discussion

We averaged RTs for correct responses in the four experimental conditions across participants and across items. The results are presented in Table 7. Lexical decisions to targets were facilitated in the identity condition (46 ms) when the primes and the targets were the same word. The important result, however, is the total lack of verbal-pattern priming. In fact, in this experiment RTs in the related condition were 4 ms slower than RTs in the control condition.

We subjected the results to a two-way ANOVA in which the prime condition was one factor and the word list was the other. The prime-condition factor was significant in both participant and item analyses, $F1(2, 90) = 50.0$, $MSE = 745$, $p < .001$; $F2(2, 90) = 41.7$, $MSE = 953$, $p < .001$. This was due only to the faster latencies in the identity condition. Planned comparisons revealed that the slight inhibition in the related condition was not significant for participants or for items ($F1$ and $F2 < 1$). The error analysis revealed a significant prime-condition factor, $F1(2, 90) = 6.32$, $MSE = 48$, $p < .002$; $F2(2, 90) = 7.6$, $MSE = 40$, $p < .008$. This was again due to the fact that participants made fewer errors in the identity condition. The number of errors in both the related conditions and the control condition did not differ significantly ($F1$ and $F2 < 1$). The prime condition had an effect on latencies of nonwords that were 15 ms faster in the identity condition, $F1(2, 90) = 5.9$, $MSE = 771$, $p < .003$, $F2(2, 90) = 3.1$, $MSE = 1{,}066$, $p < .05$. No effect was found for errors to nonwords ($F1$ and $F2 < 1$).

Experiment 3 thus provides one clear conclusion: When the order of primes and targets is reversed so that complete forms are presented as primes, the verbal-pattern priming effect does not reappear. Thus, it is not the speed of prime processing that prevents weak-root forms to prime targets from having the same verbal pattern. If the targets have a missing consonantal root, the effect vanishes, even though the verbal pattern could be extracted from the complete-

Table 6
Examples of the Stimuli Used in Experiment 3 in the Identity, Related, and Control Conditions

Experimental condition	Identity	Related	Control
Forward mask	########	########	########
Prime	hpyl, /hipil/ (*he overthrew*) הפיל (n.p.l., נ.פ.ל)	hspyk, /hispik/ (*he managed*) הספיק (s.p.k., ס.פ.ק)	nkpl, /nikpal/ (*was doubled*) נכפל (k.p.l., כ.פ.ל)
Target	hpyl הפיל	hpyl הפיל	hpyl הפיל

Note. Forward mask composed of hash marks.

Table 7
Reaction Times (RTs, in Milliseconds) and Percentage Errors for Lexical Decisions to Target Words and Nonwords in the Identity, Related, and Control Conditions of Experiment 3

Condition	Words	Nonwords
Identity		
RT	542	620
% Errors	4.8	13.5
Related		
RT	592	637
% Errors	9.5	14.3
Control		
RT	588	635
% Errors	8.7	14.3

Note. Primes were composed of complete roots, and targets were composed of weak roots. Identity priming: 46 ms; related-weak–root priming: −4 ms.

form prime and the targets have ample time to be processed by the participants. This outcome is consistent with a nondecomposability account of weak verbal forms.

Experiment 4

Before reaching firm conclusions about the nondecomposability of verbal forms that miss one root radical, a methodological concern should be raised. As we clarified in the *Method* section of Experiment 1, the verbal forms that have weak-root consonants are those conjugated with the HI--I-, HU--A-, and NI--A- patterns. This necessarily creates an experimental design in which several target words that are conjugated with the same verbal pattern are presented consecutively. This perhaps could have contributed to the weakening of the priming effect. If many consecutive prime–target pairs belong to the same pattern, then the extraction of this morpheme from the prime may become less and less informative, and targets may eventually cease to benefit from it. To overcome this pitfall, in Experiment 4 we examined the weak-root priming effect with additional fillers conjugated with the -U-A, I-E-, or HIT--AE- patterns. These patterns were conjugated with complete roots, creating a form of a mixed design, similar to Experiment 1. This provided a richer set of stimuli and prevented long sequences of primes–targets belonging to the same pattern. Our aim in this experiment was to examine whether this would restore the verbal-pattern priming effect.

Method

Participants. The participants were 48 undergraduate students at Hebrew University, all native speakers of Hebrew, who took part in the experiment for course credit or payment. None of the participants had taken part in the previous experiments.

Stimuli and design. The stimuli consisted of 48 target words that were verbal forms conjugated with weak roots and derived from the base forms (past, singular, masculine) of the verbal patterns HI--I-, HU--A-, and NI--A-. In addition, we added as fillers 16 target words conjugated with the -U-A-, I--E-, or HIT--AE- patterns. These fillers were derived from complete roots. Targets were four to five letters long and contained two syllables with four to five phonemes. Each target word was paired with three primes to form the identity, related, and control conditions. As in Experiment 2, the primes in the related condition were also weak-root forms, having an identical phonological structure, keeping phonological similarity maximal in this condition. Primes and targets overlapped by two or three letters across the three conditions, and the position of overlapping letters and phonemes in the related condition and the control conditions was always initial (given the patterns used) but could be also middle or final, with similar distributions in the related condition and the control condition.

Each target word and its prime were paired with target and prime nonwords composed of the same word patterns as above, but with nonexisting roots. As with the word targets, the nonwords too were divided into three experimental conditions mimicking the orthographic features of the words' conditions. The stimuli were divided into three lists. Each list contained 16 words and 16 nonwords in each of the three experimental conditions. The stimuli were rotated within the three conditions in each list in a Latin square design. Sixteen different participants were tested on each list, performing a lexical decision task. The procedure and apparatus were identical to those of Experiments 1–3.

Results and Discussion

We averaged RTs for correct responses in the three experimental conditions across participants and across items. The results are presented in Table 8. As in the previous experiments, lexical decisions to targets were facilitated in the identity condition (34 ms) when the primes and the targets were the same word, $F1(2, 90) = 19.7$, $MSE = 904$, $p < .001$, and $F2(2, 90) = 21.1$, $MSE = 1{,}150$, $p < .001$, for RTs, and $F1(2, 90) = 6.5$, $MSE = 63$, $p < .002$, and $F2(2, 90) = 7.2$, $MSE = 57$, $p < .001$, for errors. The important result, however, is the almost-identical latencies in the related condition and the control condition, with no verbal pattern priming whatsoever, thus replicating the results of Experiment 2. The prime condition had no effect on latencies or errors to nonwords ($F1$ and $F2 < 1$).

These results provide yet another replication of the basic phenomenon revealed consistently across our study. Verbal-

Table 8
Reaction Times (RTs, in Milliseconds) and Percentage Errors for Lexical Decisions to Target Words and Nonwords in the Identity, Related, and Control Conditions of Experiment 4

Condition	Words	Nonwords
Identity		
RT	540	621
% Errors	7.1	13.9
Related		
RT	573	619
% Errors	11.0	13.4
Control		
RT	574	620
% Errors	12.9	11.4

Note. Primes and fillers were composed of weak roots, when fillers were added. Identity priming: 34 ms; related-weak–root priming: 1 ms.

Table 9
Examples of the Stimuli Used in Experiment 5 in the Identity, Related, and Control Conditions

Experimental condition	Identity	Related	Control
Forward mask	########	########	########
Prime	hspyk, /hispik/ (*he managed*) הספיק (s.p.k., ס.פ.ק)	hlgyʃ, /hilgiʃ/ הלגיש (l.g.ʃ., ל.ג.ש)	htkgʃ, /hitkageʃ/ התקגש (k.g.ʃ., ק.ג.ש)
Target	hspyk הספיק	hspyk הספיק	hspyk הספיק

Note. Forward mask composed of hash marks.

pattern priming does not occur when the verbal forms miss one consonantal root. Experiment 4 clarifies that this outcome cannot be attributed to the constrained number of patterns used in the experiment. We thus conclude that it has a linguistic origin. We will refer to this issue in length in the General Discussion section.

Experiment 5

In Experiment 5 we created pseudoverbs by substituting the weak radical in our missing-root verbal forms with one random consonant. Thus, our primes had the morphophonological structure of complete-root verbal words but had no meaning. If having a three-consonantal structure is a necessary condition for morphological decomposition, then the pseudoverb primes should be easily decomposed into their constituent morphemes. This process should be reflected in a verbal-pattern priming effect. Note that, by this view, the meaningfulness of the triconsonantal root (and, consequently, of the entire verbal form) is not crucial for the process of decomposition. This process would then depend primarily on detecting an abstract morphophonological structure and not on recognizing a specific phonological (or orthographic) sequence that represents a meaningful root.

Method

Participants. The participants were 48 undergraduate students at Hebrew University, all native speakers of Hebrew, who took part in the experiment for course credit or payment.

Stimuli and design. The stimuli consisted of 48 pseudoword primes paired with 48 targets that were regular verbal forms conjugated with complete roots. We composed the primes by conjugating nonsense triconsonantal roots with a legal verbal pattern. Targets were four to five letters long with five to eight phonemes. Each target word was paired with three primes to form the identity, related (same verbal pattern), and control (different verbal pattern) conditions. Primes and targets overlapped by two or three letters across the three conditions, and the position of overlapping letters and phonemes in the related condition and the control condition was always initial but could be also middle or final, with similar distributions in the related and the control conditions. An example of the stimuli used in the experiment is presented in Table 9.

As in the previous experiments, 48 target nonwords were generated. The nonwords too were divided into three experimental conditions mimicking the orthographic features of the words' conditions. The stimuli were divided into three lists. Each list contained 16 words and 16 nonwords in each of the three experimental conditions. The stimuli were rotated within the three conditions in each list in a Latin square design. Sixteen different participants were tested on each list, performing a lexical decision task.

Results

We averaged RTs for correct responses in the four experimental conditions across participants and across items. The results are presented in Table 10. Lexical decisions to targets were facilitated in the identity condition (51 ms) when the primes and the targets were the same word. We were mostly concerned, however, with the potential priming in the related condition. There was a clear priming effect: RTs were faster by 14 ms in the related condition than in the control condition.

We subjected the results to a two-way ANOVA in which the prime condition was one factor and the word list was the other. The prime-condition factor was significant in both participant and item analyses, $F1(2, 90) = 40.4$, $MSE = 841$, $p < .001$, and $F2(2, 90) = 47.2$, $MSE = 855$, $p < .001$. Planned comparisons revealed that the difference between the related condition and the control condition was indeed significant for both participants and items, $F1(1, 45) = 6.3$, $MSE = 753$, $p < .01$, and $F2(1, 45) = 5.1$, $MSE = 853$, $p < .03$. The error analysis revealed a significant prime-condition variable as well, $F1(2, 90) = 9.1$, $MSE = 48$, $p < .002$, and $F2(2, 90) = 7.4$, $MSE = 59$, $p < .001$. This was mainly due to the fact that participants made fewer errors in the identity condition. Planned comparisons on the error data showed that the difference between the related condition and the control condition did not reach statistical significance for participants or for items, $F1(1, 45) = 2.9$, $MSE = 46$, $p < .1$, and $F2(1, 45) = 2.0$, $MSE = 66$, $p < .16$.

In contrast to the word targets, nonword targets did not reveal any significant effect for RTs, $F1(2, 90) = 1.4$,

Table 10
Reaction Times (RTs, in Milliseconds) and Percentage Errors for Lexical Decisions to Target Words and Nonwords in the Identity, Related, and Control Conditions of Experiment 5

Condition	Words	Nonwords
Identity		
RT	550	623
% Errors	6.0	9.1
Related		
RT	587	630
% Errors	9.5	7.4
Control		
RT	601	631
% Errors	11.9	8.2

Note. Primes were pseudoverbs composed of triconsonantal nonsense roots, and targets were regular, meaningful complete-root forms. Identity priming: 51 ms; related priming: 14 ms.

$MSE = 716, p < .25$, and $F2(2, 90) = 1.3, MSE = 673, p < .28$, or errors ($F1$ and $F2 < 1$).

Discussion

The results of Experiment 5 are straightforward: A random addition of a consonant instead of a weak radical to create a pseudotriconsonantal verbal form restored the verbal-pattern priming effect. Thus, the parsing system does not need to detect a meaningful root in order to decompose the verbal form. This outcome suggests that the system searches for a phonological structure that contains the sequence of consonants and vowels of one of seven verbal patterns, plus three consonants. When this constraint is satisfied, morphological decomposition occurs, and verbal priming is obtained. The results of Experiment 5 thus concur with previous findings from our laboratory showing verbal-pattern priming of 14–15 ms when complete pseudoverbal form primes are used (Deutsch et al., 1998).

It is interesting that the effect is not obtained when the targets are nonwords. Both the word and the nonword stimuli had nonword primes. Even though the target pseudoverbs could be decomposed into a nonsense root and a verbal pattern, verbal-pattern priming did not occur. This results reinforces our assumption that the facilitation we obtain in masked priming reflects a purely lexical processes. Thus, nonwords cannot benefit from priming in our task.

General Discussion

In the present study we examined the decomposition of verbal forms into their morphemic constituents: roots and verbal patterns. Our manipulation consisted of monitoring the facilitation in processing target words that are primed by verbal forms having identical verbal patterns. Previous studies in Hebrew have shown a consistent and robust verbal-pattern priming effect when primes and targets were complete forms (Deutsch et al., 1998; Frost et al., in press). In the present experiments we extended our research to examine the decomposition of verbal forms that have one consonant missing because they are derived from Hebrew weak roots. Our results seem to present a clear-cut picture: Whenever the primes or the targets consisted of forms with a missing consonant, the verbal-priming effect simply collapsed.

Experiment 1 presented a direct contrast between complete forms and weak forms. Whereas the complete forms revealed a strong verbal-priming effect, the weak forms revealed a small and nonsignificant facilitation. Experiment 2 demonstrated that this difference cannot be attributed to simple phonological factors. Thus, when both primes and targets consisted of forms conjugated with weak roots and had an identical syllabic structure, the verbal-pattern priming effect was not restored. In Experiment 3 we found that the detrimental effect of weak forms on verbal-pattern priming is symmetrical for primes and for targets. Hence, if the primes or the targets consisted of forms with weak roots, there was no evidence for morphological priming. This suggests that the absence of the priming effect that is usually observed between regular complete prime–target pairs is not related to the speed of processing the primes but reflects a basic difference between complete forms and weak forms. Finally, these findings were replicated in Experiment 4, in which several other verbal patterns were used as fillers to increase the external validity of our experimental setting. The outcome of weak-root priming across the four experiments is summarized in Table 11. The mean facilitation obtained when the data of the four experiments are collapsed was 2 ms. These results stand in sharp contrast to the results we obtained with complete forms in the present study (17 ms) as well as in the Deutsch et al. (1998) study (about 14–15 ms, on average).

Yet the more dramatic finding is the reinstatement of the verbal-pattern priming effect in Experiment 5. The results of this experiment demonstrated that once the weak form is made complete by inserting a random consonant into its phonological structure, the verbal-priming effect re-emerges. The important feature of Experiment 5 is that the added random consonant did not create a meaningful root but merely restored the common Semitic triconsonantal structure. Thus, the primes of Experiment 5 were pseudoverbs without any meaning. Nevertheless, they could be easily decomposed into a triconsonantal structure corresponding to a root form and a verbal pattern. This slight change in the stimuli was sufficient to produce verbal-pattern priming.

In general, the verbal-pattern priming effect may be accounted for by postulating a model in which verbal patterns are represented on the subword morphological level while assuming that all verbal forms derived from the same verbal pattern morpheme are linked to that shared morphological unit. We described a model along these lines in our previous work (Deutsch et al., 1998). This model consists of a multilevel system, including a word level (nouns and verbs) and a subword morphological level of root and verbal-pattern morphemes. By this view, all word units (both nouns and verbs) are connected to root morphemic units, whereas the verbal forms are also connected to verbal-pattern units. This model is essentially a dual-route model in the sense that the process of lexical access may consist of both a lexical retrieval process and a morphological decomposition process. The former involves the search for or activation of lexical units at the word level, whereas the latter involves the extraction of morphemic constituents. In the case of verbal forms, both the root and the verbal pattern

Table 11
Effects of Weak-Roots Priming and Complete-Roots Priming Across Experiments

Experiment	Weak roots	Complete roots
1: Prime weak, target complete	6	17
2: Prime weak, target weak	5	—
3: Prime complete, target weak	−4	—
4: Prime weak, target complete; fillers added	1	—
5: Prime complete, target complete; primes are pseudoverbs	—	14
M	2	15

Note. Dashes indicate data that were not obtained.

are extracted and located in the subword morphological level. These two processes may occur in parallel and may aid each other through bidirectional connections between the two levels.

In this context another important distinction between nominal and verbal forms should be made. The extraction of the root morpheme from nominal forms seems to require a parallel access of the whole word unit. This constraint was inserted into our model because root-priming effects were not observed for nominal forms when the primes consisted of pseudowords composed of a nonexisting combination of legal roots and legal word patterns (for a comprehensive discussion of this result, see Frost et al., 1997). This constraint, however, was not inserted into our model of the verbal system, because priming of verbal forms was unaffected by the lexicality of the primes. Thus, both derivational morphemes (roots and verbal patterns) appearing in the prime were found to facilitate the recognition of verbal targets, regardless of the prime's lexical status (Deutsch et al., 1998). Consequently, the lexical architecture that emerged from our previous investigation involved a whole-word level of representation for nominal forms, but not necessarily for verbal forms. Our previous findings concerning the verbal system could be easily accounted for by assuming activation of subword morphemic units only.

In the present study we attempted to further investigate the algorithm of the decomposition process while considering the nonconcatenative derivational morphology of Hebrew. The absence of a morphological priming effect for verbal forms derived from weak roots clarifies some of the conditions that constrain the process of extracting their morphemic constituents. Our investigation clearly indicates that when the extraction of the root morpheme is obscured because of a missing consonant, the process of decomposition is inhibited. Because weak-root targets are eventually recognized even without morphological decomposition, it seems that whole-word representations must exist for these weak forms. Thus, the results of the present study add another building block to our lexical architecture. We should emphasize, however, that our findings do not necessarily imply that regular verbal forms are represented and accessed in a similar way. This issue obviously deserves further investigation.

In regard to the decomposition process itself, the results we obtained with weak roots lead us to suggest that the parsing algorithm deals first with a purely structural problem: What are the three consonants of the root, and what are the consonants and vowels of the verbal pattern? Thus, the process of morphological decomposition entails a search for the purpose of simultaneously identifying two different morphological structures.[5] Only when the parsing system finds a satisfactory solution for both searches does decomposition occur. The output of this initial phase provides a potential root to be identified in the lexicon and provides the verbal pattern with which the potential root is conjugated. In that respect the "solution" for the roots and the "solution" for the verbal patterns are qualitatively different. For the roots, the constraint imposed on that first phase of parsing is exclusively structural (and therefore abstract), not lexical, because the parsing system apparently does not need to extract or converge on an existing meaningful root. All it requires is a triconsonantal structure. In contrast, for the verbal pattern the parsing algorithm needs to converge on one of the seven patterns. This is probably why even pseudowords composed of pseudoroots would still allow verbal pattern priming to occur. When such pseudoverbs are presented, the parsing system has a valid decompositional solution: the extraction of a triconsonantal structure for the root and a valid verbal pattern. Once this initial parsing stage is completed, a root morpheme may be lexically identified.

The different level of specificity required for extracting the root unit as opposed to the verbal-pattern unit (an abstract structural principle vs. a specific phonological structure) probably derives from the distributional properties of these two types of morpheme in the Hebrew language. There are a few hundred different roots, with very few constraints concerning their possible consonantal combinations. In contrast, there are only seven verbal patterns. Thus, whereas the repeated element with respect to the roots is a structural component of unspecified combinations of three consonants, the repeated element for the verbal patterns is one of a few specific, very familiar phonological entities. The recognition of verbal patterns is, therefore, a simpler computational process because of their limited number and their distinctive invariant phonological characteristics.

This dynamic model clarifies why verbal-pattern priming is not obtained with weak-root forms. When weak roots are presented, the constraint of a satisfactory solution for both a root structure and a verbal pattern is not satisfied. If three consonants are assigned to the root, then the parsing system cannot converge on an existing verbal pattern. On the other hand, if the respective consonants are assigned to the pattern components, then there are fewer than three consonants to be assigned to the root structure. This breakup of the initial parsing phase seems to prevent morphological decomposition, and verbal-pattern priming does not occur.

One interesting question to be explored while considering the decomposition process is the time course of availability of the two constituent morphemes: the root and the verbal pattern. One possibility is that one morpheme is located first, and the extraction of the second morpheme follows the successful extraction of the first one. Given the relative greater importance of root morphemes in Semitic languages, and their role as an organizing principle in both the nominal and the verbal systems, it would seem more probable that the initial search would focus on a root structure. By this view, no verbal-pattern priming is obtained for weak forms,

[5] We assume that the process of morpheme extraction in Hebrew must involve a phonological level of description. When word pattern morphemes are concerned, their internal structure in unpointed Hebrew is not fully depicted by the printed letters. Thus, any observed verbal-priming effect cannot be attributed to simple orthographic representation. As for the roots, their definition as a triconsonantal structure necessarily invokes a level of phonological description. Furthermore, the example of mute roots demonstrates that if a phoneme is written but phonologically absent it cannot induce morphological priming.

because after three consonants have been assigned to the root a verbal pattern cannot be easily recognized from the remaining phonemes. One shortcoming of such a parsing procedure is that it needs to specify an algorithm by which consonants in a verbal form are assigned to the root morpheme and not to the verbal pattern. An alternative possibility is that the searches for locating a root structure and a verbal pattern occur in parallel and that these two processes are interdependent and require mutual feedback. By this view, decomposition of weak forms collapses, because one consonant is missing for defining adequate solutions for the root structure and the verbal-pattern morpheme.

Some converging evidence concerning the priority in searching for a triconsonantal root structure in decomposing Hebrew words was suggested by Feldman, Frost, and Pnini (1995), who examined the processing of word pattern morphemes in the nominal system using the segment-shifting task (see Feldman, 1991, 1994; and Stolz & Feldman, 1995, for a similar manipulation in English). Feldman and her colleagues showed that the decomposition of nominal forms into their constituent morphemes was faster for words composed of transparent and productive roots than for words in which the root morpheme was not transparent. Because in the nominal system the parsing of words into roots and word patterns involves greater complexity than in the verbal system (there are more than 100 nominal patterns), the saliency of the triconsonantal structure seemed to have facilitated this decomposition process.

As in our previous discussions of Hebrew morphology (Deutsch et al., 1998; Frost et al., 1997), our model and the terms we use in our description of decomposition processes are compatible with a localist view of the mental lexicon. In this respect our account is similar to the classical models of morphological processing (e.g., Burani & Laudanna, 1992; Fowler, Napps, & Feldman, 1985; Marslen-Wilson et al., 1994; Taft, 1994). The working hypothesis underlying these models is that morphemic units are explicitly represented in the mental lexicon, such that morphological representations are discrete and nondistributed. In contrast, recent Parallel Distributed Processing (PDP) models of morphological processing describe a lexical structure in which word units are not explicitly represented and the process of word recognition entails the setting of a mutually consistent pattern of activation over processing units that correspond to the orthographic, phonological, and semantic features of the word (e.g., Seidenberg, 1987). The learning process of this system consists of attuning the reader to the statistical regularity that emerges between these various sublexical features (see, e.g., Plaut & Shallice, 1993; Seidenberg & McClelland, 1989; Van Orden, Pennington, & Stone, 1990). Thus, when morphological processing is concerned, nonlocalist models suggest that many (if not all) of the morphological effects previously reported in the literature reflect a fine-tuning of the reader's or speaker's awareness of the correlations that exist among the phonological, orthographic, and semantic properties of words (e.g., Seidenberg, 1997). In this approach there is no level of explicit and discrete representation that corresponds to morphological units. All that can be said is that a level of hidden units picks up the correlations between phonology and semantics or orthography and semantics, and these underlie the morphological effects (Rueckl, Mikolonski, Raveh, Miner, & Mars, 1997; Seidenberg, 1997).

Although localist and distributed approaches to lexical structure are opposing paradigms (see Besner, 2000; and Forster, 1994, for a discussion), distinguishing between them on the basis of pure empirical evidence is not a simple matter. Where morphological processing is concerned, the localist view and the parallel-distributed approach often yield similar predictions. For example, whereas localist models would describe morphological priming as a facilitation effect due to the lexical interconnection between morphologically related words, PDP models would describe the same effect as a result of weight changes in the connections among the semantic, orthographic, and phonological layers, given the repeated exposure of the speaker to words that have similar forms and similar meaning. Our results, however, may provide some novel insight into this debate. One major difference between the distributed approach and the localist approach is the general pattern of morphological facilitation. Because localist models assume that morphological effects in visual word recognition emerge because morphologically related words are interconnected in the lexicon directly (or indirectly, through their shared morphemes), they generally regard the occurrence of morphological priming as an all-or-none cognitive event that reflects the existence or nonexistence of these morphological connections. In contrast, PDP models focus on the amount of correlation between sublexical units. This correlation is basically continuous and nondiscrete in character. Thus, in general, any morphological effect that reveals a prerequisite all-or-none constraint is less compatible with a distributed approach (for a programmatic discussion, see Marcus, Brinkmann, Clahsen, Weise, & Pinker, 1995).

Returning to our present experimental manipulation, from the perspective of PDP models the number of root consonants that are repeated over and over in all of the root derivations is not a factor that should affect performance in morphological tasks. What determines morphological relatedness is the correlation of orthographic (and phonological) units with semantic features. Whether the repeated units consist of two or three consonantal letters should have very little effect. Consider, for example, the following inflections and derivations of the weak-root *BYN* (conveying the meaning of "understanding": */HABANA/* (*understanding*), */TOBANA/* (*insight*), */TBUNA/* (*wisdom*), */NABON/* (*wise*), */HEBIN/* ("he understood"), */YABIN/* ("he will understand"), or */HUBAN/* ("it was understood"). All of these forms share the two consonants *B* and *N* (the letter *B* is pronounced like a soft *V*). A connectionist distributed approach that considers the distributional properties of morphemic units focuses on the orthographic and phonological clusters that tend to be repeatedly associated with the same, or similar, semantic correlates. From this perspective the only difference between *HEBIN*, the weak-root derivation, and *HIKRIB*, the complete-root derivation, is that *HIKRIB* contains a cluster of three consonants (K.R.B) that appears repeatedly in many Hebrew words that have similar meanings, whereas *HEBIN* contains a cluster of two consonants (B.N) that appears consistently in all possible derivations. PDP models would in principle treat the weak and complete roots alike, thus predicting priming effects for both. The results from Experiments 1–4 clearly show that this is not the case.

Even more damaging to the distributed approach are the results of Experiment 5, which demonstrate that an insertion of any random consonant that preserves the abstract triconsonantal structure reinstates the verbal priming effect. As PDP models focus on the correlation between sublexical orthographic and semantic units, this outcome presents a genuine mystery. If any random consonant reinstates morphological priming, then this cannot be due to a correlation between specific orthographic–phonological units and semantic features. Thus, it seems that, at least where Hebrew is concerned, PDP models would have a much greater difficulty in accounting for morphological masked-priming effects.

The present investigation reveals a major constraint of morphological decomposition in a nonconcatenative morphology such as Hebrew. The processing system seems to mandatorily search for a triconsonantal root unit within the word. This suggests that native speakers of the language have some abstract structural representation of the basic morpheme with which most words are combined: the root morpheme. The all-or-none pattern of results obtained in our study is more characteristic of discrete, rule-based behavior than of simple correlational systems.

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