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Decomposing Words Into Their Constituent Morphemes: Evidence From English and Hebrew

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Participants segmented and shifted a sequence of letters from a source word to a target word and then named the product aloud. Morphemic and nonmorphemic letter sequences (e.g., *EN*) from phonemically matched words such as HARDEN and GARDEN were compared. In 4 experiments, naming latencies were faster for morphemic sequences than their nonmorphemic controls in both English, in which the morphemic status of the shifted sequence was varied and sequences were appended after the base morpheme (linearly concatenated), and in Hebrew, in which morphological transparency of the root (base morpheme) was varied and 1 morpheme was infixed inside the other (nonconcatenative) so that the phonological and orthographic integrity of the morphemic constituents was disrupted. Moreover, the likelihood with which both affixes and bases combine to form words influenced segment shifting times. In conclusion, skilled readers are sensitive to the morphological components of words whether or not they form contiguous orthographic or phonological units.

Speakers and readers possess knowledge about what words mean and how they sound, and this knowledge constitutes the mental lexicon. A major theme for theories of language processing is how lexical knowledge is organized. One crucial line of inquiry focuses on units and contrasts word- and morpheme-based accounts (e.g., Caramazza, Laudanna, & Romani, 1988). Related to the morphological units position is the issue of how regular and irregular morphological formations are represented in the lexicon (e.g., Fowler, Napps, & Feldman, 1985; Pinker, 1991; Stemberger & MacWhinney, 1986, 1988). A second line of investigation distinguishes between units for access and units for representation. Proponents of the full word position (e.g., Butterworth, 1983) claim that words composed of several morphemes (morphologically complex) are represented in the lexicon as are morphologically simple words, without regard to morphological structure. In fact, some theorists (e.g., Seidenberg, 1987; Seidenberg & McClelland, 1989; but see Rapp, 1992) have claimed that morphological effects can be accounted for in terms of similar form, or similar meaning, or both without invoking morphological units at all. By this account, morphological effects reflect the covariation of form and meaning that characterizes a language. By contrast, morpheme-based accounts (e.g., Feldman, 1994; Laudanna, Badecker, & Caramazza, 1992; MacKay, 1978) focus on the facilitatory or inhibitory interaction among morphemic units in the lexicon. Issues of lexical representation may or may not be logically dissociable from issues of units for lexical access (Henderson, 1985). Nevertheless, it is sometimes claimed that prefixes are stripped from complex words and that decomposition to a base morpheme is necessary before access to the lexicon can occur (Taft, 1979; Taft & Forster, 1975). Alternatively, it is sometimes claimed that constituent structure does not reliably influence access (e.g., Henderson, Wallis, & Knight, 1984; Manelis & Tharp, 1977; Rubin, Becker, & Freeman, 1979). In summary, in part because different theorists are searching for different types of morphological effects and in part because other relevant variables may have been confounded with morphology (see Henderson, 1985; Smith, 1988), the status of morphemes as psychologically relevant structures in word recognition is not unambiguous.

Across languages, the structure and the prevalence of morphologically complex words vary. In *isolating* languages such as Chinese or Vietnamese, words tend to be monomorphemic and cannot systematically be analyzed into smaller meaningful components. By definition, morphemes in isolating languages tend to be represented as physically distinct units. In *agglutinating* languages such as Turkish, morphological elements are appended to a base form, although the particular

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form of the affix may be phonologically and orthographically modified by properties of the base morpheme. In *inflecting* or fusional languages such as English and Hebrew, words are sometimes composed of multiple morphemes, but the boundary between morphemes is not always straightforward. Stated generally, across languages, words differ with respect to the phonological and orthographic variability of their morphemes, and this influences the salience of their segmentability into constituent morphemes (Comrie, 1981). This structural variation may have implications for how the components of a word are processed.

Morphological Processing in Concatenative Languages

The most common type of morphological formation in inflecting languages consists of affixation of an element to a base morpheme (Matthews, 1974). Affixation encompasses three processes that are defined by the position in which the affixation occurs. These include prefixation, suffixation, and infixation, respectively, in positions initial, final, and internal to the base morpheme. By definition, prefixation and suffixation entail the linear concatenation of elements, whereas infixation is nonconcatenative insofar as the integrity of the base morpheme is disrupted. The tendency in English and other Indo-European languages is to concatenate (prefixes and) suffixes to the base (and to retain the base morpheme intact). Hebrew, by contrast, relies on the intertwining of two morphemes: a skeleton of consonants (i.e., root) and a phonological pattern of vowels[1] (i.e., the word pattern; McCarthy, 1981). When a word pattern is infixed within the root, the integrity of the root morpheme is necessarily compromised relative to concatenated combinations. English and Hebrew contrast, therefore, in the principle by which morphological units are combined, and this may have implications for how lexical access for words composed of multiple morphemes occurs in the two languages.

Alternatively, it is possible that morphological effects reflect representation in the lexicon such that contrasts between the affixing inflectional morphology of English and the infixing (and affixing) inflectional morphology of Hebrew pose no special problem. The appeal to abstractness of lexical representations across types of inflecting languages is intended to parallel the argument across modality of presentation, whereby access representations but not lexical representations for visual and auditory forms are distinct (Marslen-Wilson, Tyler, Waksler, & Older, 1994). The experimental evidence in concatenative languages for lexical representation of morphology is based primarily but not exclusively on visual word recognition methodologies and how the pattern of decision latencies is influenced by (a) the particular combination of morphological components; (b) the frequency or productivity of constituent morphemes; or (c) repetition, across successive trials, of a morphological component. Some theorists capture knowledge about morphology in terms of lexical representations in which component structure is morphologically decomposed (e.g., Caramazza et al., 1988). Other theorists capture knowledge about morphology in terms of a principle of lexical organization among full forms that are morphological relatives (e.g., Lukatela et al., 1987; Lukatela, Gligorijević, Kostić, & Turvey, 1980). For example, in Italian, rejection latencies in a lexical decision task for nonwords composed of illegal combinations of real morphemes (viz., verbal stems and affixes) vary as a function of the type of violation between stem and affix (Caramazza et al., 1988). Similarly, in a phoneme monitoring task with Dutch materials, the identification of words that include stems and prefixes is easier than that of words composed of stems without a prefix (Schriefers, Zwitserlood, & Roelofs, 1991). Moreover, rejection latencies for Dutch pseudowords are sensitive to the productivity of their morphemic components (Schreuder & Baayen, 1994). These studies provide evidence of the psychological reality of the morpheme as a subword unit that cannot be purely prelexical in locus because latency is sensitive to the combination of morphemes.

It is also the case that decision times for morphologically complex forms in English are influenced by the cumulative frequency of all forms that include its base as well as by the surface frequency for that particular form (Taft, 1979). This is true both when the shared base morpheme differs in spelling (Kelliher & Henderson, 1990) and when spelling is preserved (Katz, Rexer, & Lukatela, 1991; Nagy, Anderson, Schommer, Scott, & Stallman, 1989; Taft, 1979). Similar effects have also been observed in Italian (Burani, Salmaso, & Caramazza, 1984). Evidently, morphological knowledge can be represented in a manner that is sufficiently abstract to tolerate changes in surface form. Moreover, the morphological mechanism is sensitive to the frequency with which a base morpheme appears across words and to the number of formations into which an affix enters.

Finally, in the repetition priming task, decision latencies to English words (e.g., CAR) preceded earlier in the list by a morphological relative (e.g., CARS) were faster than to targets (a) presented for the first time (Fowler et al., 1985), (b) preceded by an unrelated word (e.g., CARD) that was orthographically similar, and (c) preceded by a semantically related word (Napps, 1989; Napps & Fowler, 1987). Similarly, in a double lexical decision task, decision latencies to unrelated prime–target pairs formed from homographic base morphemes (e.g., PORTE [doors] and PORTARE [to carry]) were slowed relative to orthographic controls (Laudanna, Badecker, & Caramazza, 1989). Moreover, for pairs formed from the same base morpheme, the effect depended on the type of morphological relation (viz., inflection or derivation) that exists between members of the pair (Laudanna et al., 1992; Marslen-Wilson et al., 1994). Finally, for derivational relatives presented in a cross-modal paradigm, the outcome depended on whether affixes preceded or followed the base morpheme (Marslen-Wilson et al., 1994). These findings suggest that a morphological principle of organization among either base morphemes or whole forms is present in the lexicon. Either activation spreads among whole word forms that share a base morpheme or morphological relatives are represented as compositional variations of the same base morpheme. Stated generally, there is experimental evidence from a variety of word recognition tasks in a variety of concatenative languages (in particular English, Italian, and Dutch) that morphemes are psychologically real and that morphological effects reflect more than simply similar meanings or similar forms.

[1] The word pattern may include a syllabic prefix or suffix in addition to the vowels that are infixed into the root.

Morphological Processing in Hebrew: A Nonconcatenative Language

Most words in Hebrew are composed of two morphemes: a root and a phonological word pattern. Although both are morphemes (Berman, 1978), the semantic contribution of each morpheme is not equal. The semantic information contributed by the root is usually more salient than that of the word pattern. The root conveys the core meaning of the words formed around it. The word pattern, by contrast, may in some cases carry nothing more than word class information. It is possible, therefore, that morphological processing in Hebrew is dominated by the semantic analysis of a word's root.[2] Consistent with this claim are findings in a repetition priming study (Bentin & Feldman, 1990) showing that effects of morphological relatedness among words that share the same root were evident, even at long lags; whereas effects of semantic association were evident only at short lags. This outcome suggests that different mechanisms underlie morphological processing and the appreciation of semantic association, even though both rely on semantic analysis of the root.

Vowels and consonants in Hebrew are not represented in print in the same manner, and this may have implications for the processing of morphological structure as well. Consonants are represented by letters. Vowels are generally depicted by diacritical marks (points and dashes) presented beneath (or sometimes above) the consonant letters, although some vowels can also be conveyed by letters. Roots are composed of consonants. Word patterns are composed mainly (but not exclusively) of vowels. It is the convention that diacritical marks are omitted from most reading material, although pointed text can be found in poetry, children's literature, and religious scripts. Stated generally, the morphological information conveyed by the Hebrew orthography is more salient and unambiguous for roots that are composed of consonants than for word patterns that are predominantly composed of vowels (see Bentin & Frost, 1995; Frost & Bentin, 1992).

In addition to the difference between roots and word patterns, morphological relatives in Hebrew and English contrast because of the process of infixation. That is, in Hebrew, the entire root does not necessarily appear as an uninterrupted phonological unit. Rather, it may be distributed across multiple syllables of the word. In its printed form, however, because vowels tend not to be represented, the root often forms an orthographic unit. For example, in printed text, ZEMER (a song) and ZAMAR (a singer) will be printed in the same (right to left) manner (i.e., זמר), although they will be pronounced differently. Because, in Hebrew, vowels tend not to be printed and because some morphologically related forms differ primarily with respect to the vowels that are infixed among the consonants that compose the root, related forms will tend to differ more with respect to their pronunciation than to their visual form. As regards the repetition priming task in Hebrew, in which successive visual presentations of words formed from the same root reduce target decision latencies, the contributions of visual and morphological factors are not easily differentiated (but see Feldman & Bentin, 1994). Materials are typically constructed so that the repeated component is the root and target facilitation is observed when that component is presented in the prime and then in the target.

The repetition priming paradigm has been used to examine morphological processing of disrupted and continuous Hebrew roots, but, as noted above, the role of word patterns in that task may be minimal. The present study used a relatively new methodology that entails manipulation of the word pattern. An examination of how word patterns and roots are processed is important because the semantic character of the word pattern is relatively indistinct as compared with that of the root. Moreover, word patterns are morphemes that are never realized as continuous orthographic or phonological sequences appended to a root.

Segment Shifting Task

Laboratory-induced errors of the type that occur in spontaneous speech (Dell, 1986; Fromkin, 1973; Stemberger, 1984) have recently been examined by means of the segment shifting task (Feldman, 1991; Feldman & Fowler, 1987). In this task, participants are instructed to segment and shift a designated segment from a source word onto a target word and to name the new result aloud as rapidly as possible. If the morphological structure of source words is analyzed and decomposed in the course of segmenting the designated segment and building up the utterance to be named, then morphological effects are anticipated in this task.

The experimental manipulation exploits the fact that the same sequence of letters (e.g., EN) can function morphemically in one source word (e.g., HARDEN) and nonmorphemically in another (e.g., GARDEN). The manipulation was designed to determine whether naming latency for a word formed from a target and a shifted segment (e.g., BRIGHTEN formed from the target BRIGHT and the segment EN) is faster if the segment comes from a source word in which it was a morpheme. It is assumed that a match between morphological components specified in the lexical representation and components designated for shifting in the present task facilitates performance in a manner in which an arbitrary (i.e., nonmorphological) segmentation could not and that the task encourages participants to draw on morphological knowledge if it is available. Comparisons between morphological and nonmorphological segments have been reported with materials and native speakers of Serbo-Croatian, which is a highly inflected language (Feldman, 1991, 1994). In all cases investigated previously, the output was a morphologically complex and real word (e.g., equivalents of BRIGHTEN), and shifting latencies to targets formed from morphemic letter sequences were faster than to those formed from nonmorphemic sequences. In the present study, we replicated the effect of morphological status of a final letter sequence in the segment shifting task with English materials and then extended those results to Hebrew morphology by exploiting its unique characteristics.

As described above, morphologically complex words in both

[2] There are cases, however, in which the word pattern has a more explicit semantic content. In these cases, it is not easy to determine which of the two morphemes dominates the semantic character of the word.

English and Hebrew are composed of two or more morphemes, although they are constructed according to two different linguistic principles. In English, as in Serbo-Croatian, discrete morphemic constituents are linked linearly. There is a base morpheme to which other elements are appended so as to form a sequence. This principle defines a concatenative morphology. In Hebrew, morphemic word patterns are infixed between the consonants of the root. This defines a nonconcatenative morphology. The aim of the present series of experiments was to manipulate the morphological properties of units in the segment shifting task in languages with concatenative (Experiments 1 and 2) and with nonconcatenative (Experiments 3 and 4) morphological systems to obtain evidence for or against the psychology reality of linguistically defined morphological units that are not necessarily coextensive with either phonological (i.e., syllabic) or orthographic units. Experiments 1 and 2 used English materials and native speakers of English, and the experimental manipulation focused on the morphological status of a letter sequence. Experiment 1 used real words as source and target items and it also encompassed an index of affix reliability, the reliability with which a particular letter sequence functions as a morpheme. Experiment 2 used the same real words as source items but used pseudowords as targets so as to eliminate interpretations on the basis of a special relationship between source words and targets. Experiments 3 and 4 used Hebrew materials and native speakers of Hebrew, and the experimental manipulation was cast in terms of root transparency of the source word, that is, the tendency for some but not all roots to combine with many word patterns. (The word pattern is always morphemic, therefore, the manipulation of morphological status is not entirely analogous to that introduced in English.) As noted above, in principle, morphological structure could become available either prelexically or be part of the lexical representation. Because morphemes are combined according to different principles in English and in Hebrew, similar outcomes across experiments and languages would provide evidence of morphological processing that is not easily described in terms of orthographic or phonological access units.

Experiment 1

The segment shifting manipulation is based on the observation that the morphemic composition of many words is not independent of lexical information. In the absence of a word context, the morphemic status of many sequences of letters is indeterminate. In the presence of a word context, some sequences may, but need not, be morphemic. Consider the status of final sequence EN in words such as GARDEN and HARDEN. The former is morphologically simple. The letter sequence is part of the unitary morpheme. The latter is morphologically complex in that the sequence EN forms a morpheme that is affixed to the base morpheme HARD. In short, whether or not EN is a morpheme depends on the particular word to which it is affixed. In Experiment 1, ambiguity of morphological status for sequences of letters was exploited to probe morphological processing. In particular, if language users have access to the morphological structure of words while performing the segment shifting task, then segmenting and affixing morphological segments may be easier than segmenting and affixing morphologically arbitrary but phonemically equivalent segments. Moreover, if the effect reflects affixation procedures, then compatibility between word class of source word and target word may be relevant. Alternatively, if the effect is dominated by segmentation (or decomposition) procedures on the source word, then properties of the affix or base morpheme (root) may be relevant insofar as they help to reveal constituent structure.

Recent work by Burani and Laudanna in Italian (Burani & Laudanna, 1992) and by Schreuder and Baayen in Dutch (1994; see also Baayen, 1992) has suggested that the reliability with which a letter sequence functions morphemically is also important in determining how morphologically complex words are processed. Although a variety of measures have been proposed (e.g., some are type based and others are token based), most consider both the number of words in which a letter sequence functions morphemically and the total number of occurrences of that sequence in some corpus. As a first approximation of morphological reliability for the English materials, the *Capricorn Rhyming Dictionary* (Redfield, 1965) was used to estimate the ratio of the number of words that end in a particular morpheme to the total number of words (without proper nouns and archaic terms) that end in that letter sequence.

Method

Participants. Forty-six American college students from an introductory psychology course at the University of Delaware participated in Experiment 1 in partial fulfillment of course requirements.

Stimulus materials. Forty source pairs of English materials were constructed. Each source pair included a morphologically complex word composed of a base morpheme and a morphological suffix and a morphologically simple control word composed of only one morpheme. The control word ended with the same sequence of letters that functioned morphemically in its counterpart complex word. Morphemic and nonmorphemic endings were matched for phonemic and syllabic overlap. Nineteen of the simple and complex source words were matched for length, although overall, the average length of the simple words was slightly shorter (6 letters) than for complex words (6.4 letters). The average surface frequency for morphologically complex source words was 19 ($SD = 42$). The average frequency for morphologically simple source words was 69 ($SD = 107$).[3] Both derivational and inflectional forms as well as morphemically complex forms that could be either inflections or derivations were included. For example, morphologically complex source word pairs consisted of inflected words such as WINNING and their phonemically matched morphologically simple counterpart such as INNING and derived words such as HARDEN and their phonemically matched morphologically simple counterpart such as GARDEN.

Members of each source pair with morphological affixes included 11 pairs with ER, including both inflectional (e.g., COLDER) and derivational (e.g., SWIMMER) functions; 6 pairs with EN that also included inflectional (e.g., DRIVEN) and derivational functions (e.g., SOFTEN); 6

[3] Zero was entered for items not listed in the frequency count. The difference in frequency between simple and complex source words may be overestimated by using surface frequency values. In fact, the average frequency of the base form from which the morphological source word was formed was 79 ($SD = 102$).

Table 1
Number of Morphemic Entries, Total Number of Entries, and Ratio of Morphemic to Total Number of Entries for the Affixes Used in Experiment 1

Affix	Morpheme	Total count	Ratio
AL	42	80	.53
EN	63	104	.61
ER	177	311	.57
EST	25	61	.41
IC	101	132	.77
ING	184	238	.77
OR	39	99	.39
STER	10	17	.59
Y	176	250	.70

pairs each with ING, which is ambiguous as to morphological type[4] (e.g., WRITING); and 6 pairs each with EST (e.g., NEATEST) and Y (e.g., LACY). In addition, there were 2 derivational pairs with AL (e.g., RENTAL); and 1 pair each with IC (viz., SCENIC), STER (viz., MOBSTER), and OR (viz., SCULPTOR). Measures of morpheme reliability for these affixes are summarized in Table 1 and are based on listings in the *Capricorn Rhyming Dictionary* (Redfield, 1965) with proper nouns, hyphenations, and archaic terms deleted. They include the total number of morphemically complex words and the ratio of morphemic to total entries.

Target words were selected so that when the morphological or nonmorphological ending was added to it, no spelling change or pronunciation change to its base morpheme was required. It was the case, however, that segmenting the affix (e.g., EN) from the morphologically complex source word (e.g., DRIVEN) sometimes required orthographic or phonological adjustments to its base (e.g., DRIVE). Source and target words were phonologically and semantically unrelated. The morphologically complex source words together with their morphologically simple controls and the target words to which the designated segment was shifted constituted a triad.

Procedure. Participants were individually tested in a dimly lit room. They sat approximately 70 cm from an Atari computer and screen and stimuli subtended a visual angle of approximately 4°. Following the procedure developed for Serbo-Croatian (Feldman, 1994), participants viewed a fixation point for 200 ms, then source words such as HARDEN or GARDEN appeared. After 750 ms, the EN was highlighted, the target word BRIGHT appeared below the source word, and a clock started. The source and target words remained visible for 1,500 ms and then a blank screen returned. The motivation for choosing a relatively long duration for the source word was to ensure that access to lexical knowledge was possible. It should be noted that the present durations work against a prelexical account of morphological processing by giving virtually unconstrained processing time as lexical access is generally available before 750 ms has transpired.

Participants were instructed to segment and shift the designated segment from the source word to the target word and to name the new result aloud as rapidly as possible. For example, participants were instructed to shift the EN of the source word GARDEN (or HARDEN) to the target word BRIGHT that appeared below it and to say the new form aloud. In each case, participants said BRIGHTEN, and onset to vocalization was measured and errors were recorded. The segment shifting procedure used in Experiment 1 is depicted in Figure 1.

Design. Two lists of items were created. Simple and complex members of a source word pair were counterbalanced across experimental lists so that half of the items in each list had each type of structure. Stated differently, a target that was preceded by a morphologically complex word in one list was preceded by a morphologically simple source word in the other, and both lists included equal numbers of simple and complex source words. Each participant saw only one list and one member of a source pair. During the course of the experimental session, therefore, each participant saw both morphologically complex and simple source words.

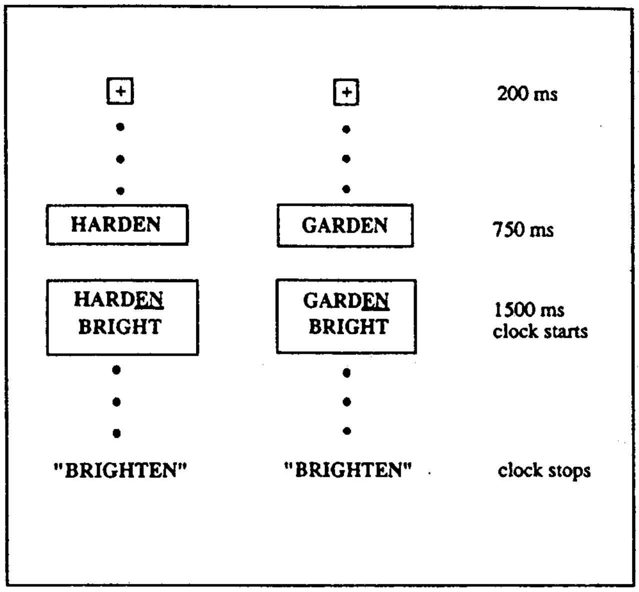

Figure 1. The segment shifting procedure for English.

Results and Discussion

Means and standard deviations of latencies for correct shifting of patterns from source words to target words were calculated for each participant in the morphologically complex and morphologically simple experimental conditions. Reaction times that were more extreme than 2.5 standard deviations from the mean of each participant in each condition were replaced by the overall mean of that condition for the analysis of variance (ANOVA) for Experiment 1. Outliers and errors accounted for fewer than 9% of all responses. Means in the complex and simple conditions were 583 ms and 598 ms, respectively. Shifting latencies were 15 ms faster to targets formed with a morphemic ending than to targets formed with a nonmorphemic ending. The statistical significance of that difference was assessed by F tests across participants (F_1) and across stimuli (F_2): $F_1(1, 43) = 8.48, p < .005, MSE = 4{,}496$; $F_2(1, 39) = 10.04, p < .003, MSE = 4{,}947$. Because of the severe constraints on creating materials in the inflectionally impoverished language of English, no comparison between types of morphological formations was possible. Error rates were 8% for both the morphologically complex and simple conditions, therefore, no analyses were performed.

The results revealed that it was easier for participants to segment and shift letter sequences from a source word to a target word when the sequence constituted a morphological unit than when it did not. This outcome indicates that skilled readers are sensitive to a word's constituent morphological

[4] For example, if WRITING is a noun, then ING forms a derivational affix. If WRITING is a verb, then ING is an inflectional affix.

structure such that lower frequency (morphologically complex) source words produced faster shifting latencies than higher frequency (morphologically simple) source words. Paired item means were used to calculate the difference in segment shifting latencies in the complex and simple conditions. The difference was not significantly correlated with the surface frequency of either the morphologically complex or the morphologically simple source word nor with the frequency of the word from which the complex source word was formed.[5] Finally, the magnitude of the difference in shifting latencies was correlated with a crude measure of morphological reliability for each affix. The correlation of shifting latencies with proportion of morphemic entries was significant ($r = .35$), $p < .05$.

It was always the case that a morphologically complex source word contained another word, specifically its base. Morphologically simple words, by contrast, were variable. For example, HUNGER and ARMY encompass other unrelated words (viz., HUNG and ARM, respectively), whereas THUNDER and BABY do not. In a post hoc analysis, we asked whether this difference had an effect on shifting latencies. Morphologically simple source words were sorted as to whether or not they contained a word internally. The magnitude of the segment shifting effect was computed separately from item means for simple source words with and without internal words. The difference in shifting latencies between simple and complex forms was 16 ms, $F_1(1, 17) = 5.24$, $p < .04$, for THUNDER-type source words and 19 ms, $F_1(1, 18) = 4.50$; $p < .05$, for HUNGER-type source words.[6] Evidently the necessary presence of a word internal to morphologically complex source words and the optional presence of a word internal to morphologically simple source words cannot account for the difference in shifting latencies for morphemic and nonmorphemic letter sequences.

Output was equated over the morphologically complex and simple experimental conditions. Therefore, results in the segment shifting task results cannot simply reflect the phonological relationship between target word (e.g., BRIGHT) and what participants produced (e.g., BRIGHTEN). Because source words were selected so that several letters close to the shifted portion were always phonologically very similar and that the shifted portion itself was identical, it is unlikely that this outcome reflects differences in phonological sequences or sequential probabilities of letters between simple and complex source words. It is possible, nevertheless, that lexical properties of the target (Dell, 1990) or a lexical editor of sorts (Dell, 1986) influences the outcome in the segment shifting task. In essence, participants may be attempting to generate a response by applying a morphological rule appropriate for a particular target.

Experiment 2

One methodological concern with the segment shifting task is the inherent similarity between the base morpheme of the morphologically complex source word and the target word to which the segment is shifted. Typically, for example, source and target words belong to the same word class in the morphologically complex condition but not in the morphologically simple condition. The aim of Experiment 2 was to determine whether word class compatibility underlies the effect observed in the segment shifting task. Note that the issue of word class compatibility is relevant to the locus of facilitation in the present task. One possibility is that it is easier to detach a letter sequence from a source word if it is a morpheme than if it is not. Alternatively, it may be easier to append the letter sequence from a source word onto a target word of the same class than onto a target of a different word. In Experiments, 2, 3, and 4, participants were required to segment and shift sequences onto target pseudowords. In this case, no privileged relation between target word and source word was present.

Method

Participants. Forty-four American college students from an introductory psychology course at the University at Albany, SUNY, participated in Experiment 2 in partial fulfillment of course requirements.

Stimulus materials. The 40 source pairs from Experiment 1 were combined with pseudoword targets. For example, morphologically complex source words consisted of inflected words such as WINNING and their phonemically matched morphologically simple pair such as INNING and derived words such as HARDEN and their phonemically matched morphologically simple pair such as GARDEN. Segments were shifted onto orthographically legal pseudowords such as REEN or EAP.

Procedure. The procedure was identical to that of Experiment 1.

Results and Discussion

Outliers were handled as in Experiment 1 and accounted for approximately 6% of the responses. Means in the morphologically complex and morphologically simple conditions were 813 ms and 833 ms, respectively. Shifting latencies were 20 ms faster to targets formed with a morphemic ending than to targets formed with a nonmorphemic ending. The difference was significant across participants and stimuli, $F_1(1, 43) = 7.97$, $p < .007$, $MSE = 10{,}516$; $F_2(1, 39) = 5.83$, $p < .02$, $MSE = 7{,}940$, in the analysis of latencies. No effects were significant in the analysis of errors, but responses for complex source words tended to be more accurate than those for simple source words. Error rates were 11% and 13% for complex and simple conditions, respectively.

As in Experiment 1, item means in the complex and simple conditions were used to compute the difference in shifting latencies for each item pair. The correlation between the magnitude of the segment shifting effect and morphological reliability was not significant, although it was in the same direction as in Experiment 1. The correlation of shifting

[5] Nor was the difference significantly correlated with cumulative frequency or with log cumulative frequency of words formed from the base of the complex source word.

[6] Three words were omitted from the analysis because they included letters in addition to an unrelated word and a potential affix. Specifically, CANDY includes D in addition to CAN and Y, CAPITAL includes IT in addition to CAP and AL, and STARLING includes L in addition to STAR and ING.

latencies with proportion of morphemic entries was $r = .22$. Following the analyses described in Experiment 1, shifting latencies were examined separately for THUNDER- and HUNGER-type source words. Morphological effects were not statistically different for simple source words in which internal structure did and did not contain another lexical item.

In effect, the same pattern of results was obtained when segments were shifted to real-word targets and when they were shifted to pseudoword targets. This finding eliminates accounts that are based on word class compatibility between source and target word in the morphologically complex condition but not in the morphologically simple condition.[7] The plausibility of a compatibility argument is further weakened by the finding that, in Serbo-Croatian, homographic morphemes (an English example is agentive and comparative ER) were shifted to appropriate targets no more quickly than to inappropriate targets (Feldman, 1991, 1994). That is, in Serbo-Croatian, shifting the nominative plural I to another noun is no faster than shifting the third-person plural I from a verb to a noun.

Experiment 3

In Experiments 1 and 2, the morphological status of a letter sequence influenced the time that participants required to produce a new form. Although it was the case that a variety of morphological patterns was examined in English, all morphological sequences and their controls took the (approximate) form of final syllables. The subsequent experiments in Hebrew were designed to probe segment shifting in linguistic environments with differing morphological characteristics (that structure is described below). The relevance of investigating the processes that underlie segment shifting in a language with a nonconcatenative structure such as Hebrew was threefold. First, the experimental manipulation was extended beyond a comparison of the morphological status of final syllables. Second, the experimental manipulation was extended to a more general characterization of morphology. Specifically, the transparency of the root as contrasted with the affix was manipulated. Third, because word patterns are distributed throughout the root, it was possible to contrast two types of to-be-shifted segments: (a) word patterns that are written exclusively as diacritics and disrupt only the phonological integrity of the root, and (b) word patterns that are written with a combination of diacritics and letters and disrupt both the phonological and orthographic integrity of the root. This comparison is not possible in English.

In Hebrew, roots and word patterns are abstract in that only by virtue of their joint combination (together with the application of phonological and phonetic rules) are specific words formed. Although word patterns carry morphosyntactic and some semantic information, their meaning is often obscure and typically changes for each root–pattern combination (see Berman, 1978). Moreover, there are no unequivocal rules for combining roots and word patterns to produce specific word meanings. For example, the word KATAVA (a newspaper article) is composed of the root KTV and the word pattern /-a--a-a/ (the dashes indicate the position of the root consonants and in this example, the second consonant is doubled). The root KTV (כתב) refers to the concept of writing, whereas the word pattern /-a--a-/ is often (but not always) used to form nouns that are the product of the action specified by the root. Other word patterns may combine with the same root to form different words with different meanings that may closely be, but may very remotely be, related to writing. For example, the word KATAV (press correspondent) is formed by combining the root KTV with the word pattern /-a--a-/. The /-a--a-/ pattern carries the morphosyntactic information that the word is a noun that signifies a profession.[8] Whereas some word patterns consist exclusively of vowels, others consist of a prefixed or suffixed consonant as well as vowels. The word KTOVET (address) is formed by combining the KTV root with a word pattern that includes a final consonant. The /--o-et/ pattern carries the morphosyntactic information that the word is a feminine noun. When the same phonological pattern is applied to other roots, it forms different verbs or nouns, each of which is related to its respective root action. For example, KTORET (incense) is formed from the KTR root together with the /--o-et/ pattern. In summary, it is the combination of root together with word pattern that specifies the meaning of a particular word.

In Experiment 3, the morphological processing of printed Hebrew words consisting of roots and infixed word patterns was investigated. Following the pointed source words, participants were presented with an unpointed pseudoroot target. They were required to detach the vowels from the previously presented source word and to read aloud the pseudoroot target using those vowels. They were instructed to proceed as rapidly as possible without making errors. The purpose of using pseudoroot rather than real roots as targets was to eliminate target-specific lexical effects from responses (i.e., naming the target word by using lexical knowledge and ignoring the source word) by forcing participants to combine the segmented word pattern and the target.[9]

The aim of Experiment 3 was to investigate the processing of word patterns that are conveyed in unpointed Hebrew exclusively by diacritic marks. By analogy with previous studies in English and Serbo-Croatian that used the segment shifting task, participants were presented with pointed source words

[7] The pseudoword finding also reduces the similarity between the present outcome and that of Manelis and Tharp (1977). In that study, faster decision latencies were observed for pairs of words with the same morphological structure (i.e., simple or complex) than for pairs with differing structures (i.e., one simple and one complex). The effects of structure were interpreted in terms of similarity of meaning between word pairs. In our study, analogous effects for word and pseudoword targets argue against interpretations based on similarity between source and target items in the morphologically complex condition but not in the morphologically simple condition.

[8] The doubling of the middle consonants in the present example is a morphological marker that distinguishes between the word pattern that specifies a profession and a similar word pattern /-a-a/, common in adjectives, that signifies attributes.

[9] The similar results of Experiments 1 and 2 suggest that the introduction of pseudoword targets is appropriate because morphological processing of word targets as required by the segment shifting task generalized to pseudoword targets.

that varied along a morphological dimension. Here, the morphological source words were polygamous in that they had three-consonant roots that appeared in other Hebrew words, and the consonants were pointed to convey a specific word pattern. That is, the root was fully transparent. The morphologically opaque words were monogamous in that they consisted of three-consonant roots that did not occur in any other Hebrew word and were pointed with the same vowel configuration as the morphologically transparent words. These were analogous with the English control words in Experiments 1 and 2. The word patterns were exclusively composed of vowels represented by diacritics, and, like the English experiment, the to-be-shifted material did not interrupt the orthographic integrity of the target words. Because Hebrew word patterns are all considered to be morphemic, in necessary contrast to Experiments 1 and 2 in which a morphologically complex–simple comparison was possible, in Experiments 3 and 4, the experimental manipulation treated morphology in a continuous manner, linking it to the root and its transparency.

If morphological processes in Hebrew entail a segmentation or decomposition similar to that of Serbo-Croatian and English, then word patterns from transparent roots should be segmented (or affixed) faster than the same pattern from an opaque root. A morphological outcome evidenced by an effect of root transparency in Hebrew would indicate sensitivity to morphemes in a nonconcatenative language and provide additional support for the lexical representation of morphological structure.

Method

Participants. Thirty-six students at the Hebrew University, all native speakers of Hebrew, participated in the experiment for course credit or for payment.

Stimuli and design. Forty triads of stimuli were constructed. Each set consisted of a word composed of a morphologically transparent root and a word pattern, a word composed of an opaque root with the same word pattern, and a pseudoroot target. The pseudoroots consisted of a sequence of three consonants that did not form a meaningful word in Hebrew by any possible vowel combination. The roots were all three consonants in length, and the word patterns always consisted of two vowels.

Within a set, the word patterns for source words with transparent and opaque roots were identical so that shifting a word pattern to a target resulted in identical phonological structures (CVCVC) in the transparent and opaque conditions. For example, a triad could consist of (a) a source noun like DEVEK (glue) that contains the transparent root DVK (the action of sticking) and the word pattern /-ɛ-ɛ-/, (b) a source noun like GEFEN (vine) that contains the three consonants GFN that do not form a transparent root and the same infixed word pattern /-ɛ-ɛ-/, (c) a meaningless target consonant string like ZTM that does not convey meaning when combined with any pattern of vowels. All source nouns, both morphologically transparent and opaque, were presented in their pointed form. The pseudoword target roots were presented in an unpointed form.

Two lists of words were constructed. A target pseudoroot that was paired with a morphologically transparent root and a particular word pattern in one list was paired with a morphologically opaque noun and the same word pattern in the other list, and vice versa. Each participant was tested on one 40-item list and was thus presented with 20 source words with morphologically transparent roots and with 20 source words with morphologically opaque roots. Eighteen participants were randomly assigned to each of the two lists.

Procedure and apparatus. Participants were individually tested in a dimly lit room. They sat approximately 70 cm from a Macintosh II computer screen so that the stimuli subtended a horizontal visual angle of approximately 4°. Because of the orthographic characteristics of the Hebrew materials, the presentation conditions were modified slightly from the English study. Following the appearance of a fixation point for 500 ms at the center of the screen, a pointed word appeared for 600 ms. Immediately afterward, the target, which was an unpointed and meaningless sequence of consonants, was presented and the source word disappeared. The target was visible for 1,500 ms. A blank field followed the display and lasted for 2,000 ms.

Participants were instructed to segment and shift the word pattern from the source word onto the target letter string and to name the new pseudoword aloud as rapidly as possible. For example, participants were instructed to shift the vowels of the source word GEFEN (or DEVEK) to the target string ZTM to produce ZETEM. Onset to vocalization was measured from the presentation of the target consonant string, and errors were recorded. The experimental session started with 16 practice trials that were followed immediately by the 40 experimental trials presented in one block.

Results and Discussion

Outliers were determined as in Experiments 1 and 2. Outliers together with errors accounted for fewer than 5% of all responses. Shifting latencies for targets formed from words with morphologically transparent and morphologically opaque roots were 607 ms and 619 ms, respectively. The shifting of vowels from words containing a transparent root was 12 ms faster than the shifting of vowels from words that contained an opaque root.

The analyses revealed an effect of morphological transparency that was marginally significant in the analysis across participants, $F_1(1, 35) = 2.60, p < .10, MSE = 591$, but was significant in the analysis across stimuli, $F_2(1, 39) = 4.10, p < .04, MSE = 659$. No effects were significant with the error measure, and the error rates averaged less than 4%.

The results seem to indicate that, when phonologically matched, word patterns can be shifted from source words to target consonant strings more rapidly if the source word includes a transparent root than if the root is not transparent. This outcome, although weak, especially across participants, is consistent with results reported previously in Serbo-Croatian and with results of Experiments 1 and 2 in English, both of which are concatenative languages. It suggests, moreover, that the variation in presentation conditions had no effect. If replicable, this outcome indicates that the component structure of morphologically complex words is represented in the Hebrew lexicon. Finally, by using pseudoroots as targets as in Experiment 2, interpretations based on similarity between the stationary portion of the source word and the target string in the transparent condition but not in the opaque condition become irrelevant.

The results of Experiment 3 with Hebrew materials in which word patterns were infixed between the consonants of a root (more precisely, pseudoroot) potentially extend the results of previous segment shifting studies. Here, the morphological manipulation was based on the transparency of the root of the source word because all shifted segments were, in fact, linguistically morphemic (i.e., there is no Hebrew equivalent of a "nonmorphological affix," more precisely, infix). This finding demonstrates a morphological effect in the segment shifting task even when morphemes are not phonologically coherent units because the root and word pattern are intertwined. It is not clear in this experiment whether the locus of the effect should be assigned to the word pattern or to the root. The logical requirements of the task directed participants to shift the word pattern from the source word to the target pseudoroot, which implies that they should focus on the word pattern. Nevertheless, it is possible that the classification of the word pattern also hinges on the transparency of the root with which it combines. Accordingly, it is important to ascertain that, along nonmorphological dimensions, source words were equated across experimental conditions.

One possible criticism of the results of Experiment 3 is that transparency and surface frequency of the source words are confounded and that segment shifting times basically reflect recognition latencies. Accordingly, faster shifting latencies for transparent root patterns occur because those words appear more frequently in print than do the words with opaque roots. Although the English results are not consistent with this account because complex source words had a lower average frequency, one alternative interpretation of the outcome of Experiment 3 is that the greater facilitation in the segment shifting task for transparent roots relative to opaque roots merely reflects enhanced processing of more familiar words in Hebrew. To explore this possibility, the subjective frequency of each word was assessed. The pointed source words used in Experiment 3 were presented to undergraduate students from the Hebrew University who rated their frequency on a 7-point scale, from 1 (*very infrequent*) to 7 (*very frequent*). The average frequencies across 50 judges were computed. On the basis of the frequency ratings, pairs of transparent and opaque source words in which frequencies were matched or, with a higher opaque frequency, were selected for further analysis. With this control for surface frequencies (20 pairs), shifting latency was again faster for words containing transparent patterns (604 ms) than for words containing opaque patterns (621 ms), $t(19) = 2.90$, $p < .01$. If anything, the effect increased in magnitude when the surface frequency of transparent words was equal to or lower than that of its opaque pair.

The same materials were presented to 40 new participants from the Hebrew University in a lexical decision task. Latencies were also faster for words in the transparent condition (577 ms) than for words in the opaque condition (602 ms). However, the difference in shifting latencies for word patterns from transparent and opaque source words was not significantly correlated with lexical decision latencies for either word type (for transparent source words, $r = .10$ and for opaque source words, $r = -.19$). Moreover, there was a suggestion that the difference between shifting latencies for the two conditions was negatively correlated with the difference in lexical decision latencies for transparent and opaque source words ($r = -.22$).[10] Consistent with the results obtained in English, the ease in shifting Hebrew word patterns from words with morphologically transparent roots relative to words with morphologically opaque roots apparently cannot be explained by frequency of forms in print. In addition, it cannot be explained by factors that produce differences in recognition (viz., lexical decision) latencies to those forms.

Experiment 4

The instructions to participants in Experiment 3 were deliberately vague. Participants were simply instructed to shift the vowels from the source word onto the target pseudoroot in a manner that formed a possible word of Hebrew. Remarkably, most participants were able to perform the task with only minimal practice, and the error rates indicate that they were quite accurate. In Experiment 3, the word pattern that participants were required to segment and infix consisted exclusively of vowels represented as diacritics. Thus, as with the segment shifting materials for analogous studies in English or Serbo-Croatian, the orthographic integrity of the target was never disrupted by shifting a pattern of vowels onto it. Stated differently, the "segment" to be shifted was always orthographically specified below the consonant letters of the source word root. Consequently, the orthographic form of the target was not disrupted by the addition of the shifted word pattern.

In Experiment 4, the morpheme manipulation was made graphemically more complex in an attempt to strengthen the outcome of Experiment 3. There exist some word patterns in Hebrew that disrupt the orthographic integrity of the root because the pattern consists of vowels that are represented by a combination of diacritics and letters. Other word patterns consist of a combination of both vowels and consonant letters appended either before or after the root. Two types of word patterns that disrupt the orthographic integrity of the root were examined in Experiment 4. One type included exclusively vowels represented by a combination of letters and diacritics. The other included a combination of pointed vowels and consonant letters. In neither case could the word patterns that were shifted in Experiment 4 be spatially defined below the root, as was the pattern of diacritics.

Method

Participants. Thirty-six students at the Hebrew University, all native speakers of Hebrew, participated in the experiment for course credit or for payment. None of the participants had participated in Experiment 3.

Stimulus materials. As in Experiment 3, 40 triads that consisted of a word with a morphologically transparent root, a word with a morphologically opaque root, and a pseudoroot target were assembled. However, in contrast to Experiment 3, all source words contained more than three letters, and their decomposition into (three consonant) roots and word patterns was, therefore, more complex. There were two types of word patterns. The first type consisted of vowels only, in which these vowels were conveyed in print by a combination of diacritical marks under the letter and additional letters that were affixed in the medial and in the final position of the word. For example, the root PRS (פרס the action of slicing]), when infixed with the word pattern /--u-ah/, specifies PRUSAH (a slice) and is written פרוסה. The vowel /u/ is represented in this case by the letter ו, the third letter of the word, and the final vowel /a/ is represented according to Hebrew spelling rules by the letter ה in word-final position. (Recall that Hebrew is read from right to left.)

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[10] The value for 38 *df* and $p < .05$ is .32.

The second type of word pattern consisted of vowels and consonants that were affixed before and after the root. For example, the root ZKR (זכר), meaning "the action of remembering," when combined with the word pattern /mɑ--ɛ-ɛt/ forms MAZKERET (a souvenir) and is written מזכרת. In this case, the word pattern consists of a prefix /mɑ/, a vowel /ɛ/ marked by a diacritic and a final suffix /ɛt/. It is important to note that both the medial–final word pattern /--u-ɑh/ and the initial–final word pattern /mɑ-ɛ-ɛt/ can participate in the formation of many Hebrew words.

The design of the segment shifting procedure required that the control source words never included a transparent root but always contained the same word pattern as the words with transparent roots. For example, the words PLUMAH (feathers) and MAKHZELET (mat) are the opaque controls for PRUSAH and MAZKERET. These words have the same word pattern as their transparent root pairs, but, because no other word is formed around the PL-M or the KHZ-L sequence, these consonant sequences are not considered to be transparent roots. As in Experiment 3, the pseudoroot targets in Experiment 4 were composed of a sequence of three consonants that did not represent a meaningful word in Hebrew with any vowel combination.

Participants were instructed to read the source word and to create from it and the target a new word that has a similar word pattern. For example, the pseudoroot BNZ should have been read BNUZAH by applying the /--u-ɑh/ pattern, and the pseudoroot KSZ should have been read MAKSEZET by applying the /mɑ--ɛ-ɛt/ pattern.

Procedure. The procedure and apparatus were identical to those of Experiment 3. Participants were instructed to segment and shift the word pattern from the source word to the target string and to name the result aloud as rapidly as possible. For example, participants saw MAZKERET and KSZ and then they produced MAKSEZET.

Results and Discussion

Two triads of stimuli were removed from the analysis because more than 50% of the participants did not apply the word patterns to their respective targets appropriately. Means and standard deviations of latencies to name pseudoword targets with the word patterns of the source word were calculated for each participant in the transparent and opaque experimental conditions according to the same criterion as that of Experiment 3. They are summarized in Table 2. Means for the transparent and opaque conditions were 781 ms and 823 ms, respectively. Based on an examination of segment shifting latencies, the word patterns included in Experiment 4 were more difficult than those of Experiment 3, and it is likely that this reflects either the graphemic or phonological complexity of the word pattern to be shifted.[11] Nevertheless, as in Experiment 3, shifting of word patterns from words containing a transparent root was faster than shifting that same word pattern from words that contained opaque roots.

The statistical significance of those differences was assessed by a two-way ANOVA with the factors of morphological transparency of source word (transparent vs. opaque) and of word pattern (vowels only vs. vowels and consonants). The analysis revealed a significant effect of morphological transparency: $F_1(1, 35) = 4.80, p < .03, MSE = 7{,}410$; $F_2(1, 36) = 5.10$, $p < .03$, $MSE = 6{,}809$. The main effect of word pattern was significant in the analysis by participants, $F_1(1, 35) = 4.80, p < .03$, $MSE = 5{,}806$, but missed significance in the analysis by stimuli, $F_2(1, 36) = 1.96, p < .17, MSE = 6{,}809$. The two-way interaction was not significant (both Fs < 1.0). With the error measure, means for the transparent and opaque conditions were 6% and 7%, respectively. Neither the main effect of word pattern nor the interaction of morphological status by word pattern approached significance with errors as the dependent measure.

Table 2
Mean Reaction Times (in Milliseconds), Standard Deviations, and Errors to Shift Word Patterns Consisting of Diacritic-Plus-Letter Vowels and Diacritic-Plus-Letter Consonants From Transparent and Opaque Hebrew Source Words in Experiment 4

Word pattern	Source word: Transparent	Source word: Opaque
Diacritic-plus-letter vowels		
M	790	842
SD	92	
ER (%)	4	4
Diacritic-plus-letter consonants		
M	773	805
SD	58	85
ER (%)	9	9

Note. ER = error rate.

To assess the contribution of surface frequency to the outcome, as in Experiment 3, 50 participants from the Hebrew University were asked to rate the frequency of all items on a 7-point scale. The effect of root transparency was examined for pairs that were matched in frequency or in which the frequency of the opaque source word was higher. The analysis was based on the 19 pairs that met these constraints and again revealed that word patterns were shifted more rapidly from source words with transparent roots (777 ms) than from source words with opaque roots (823 ms), $t(18) = 2.04, p < .05$. Thus, in replication of Experiment 3, the effect of root transparency in the segment shifting task could not be attributed to frequency differences among transparent and opaque source words.

As in Experiment 3, the materials from Experiment 4 were also presented to 40 students from the Hebrew University in a lexical decision task. Latencies were again faster for pointed words in the transparent condition (561 ms) than in the opaque condition (595 ms), and differences in shifting latencies for word patterns from transparent and opaque source words were not significantly correlated with mean lexical decision latencies for source word pairs with transparent roots ($r = .14$) or source words with opaque roots ($r = .05$). Moreover, the correlation between the differences for transparent and opaque source words in the lexical decision and segment shifting tasks was not significant ($r = .22$). Across experiments, lexical decision latencies were faster in Experiment 4 than in Experiment 3, and yet the magnitude of the segment shifting effect was enhanced.

In summary, the results of Experiment 4 are consistent with the segment shifting results of Experiments 1–3. Segment shifting latencies were slower overall, but morphological effects were statistically significant, whereas previous compari-

[11] The word patterns were not spatially defined as they included letters in addition to diacritics positioned under letters. They also included more syllables than in Experiment 3.

sons in Experiment 3 were marginal. With Hebrew materials, word patterns from transparent roots were shifted faster than from opaque roots, and orthographic familiarity of the surface forms was not relevant.

The effect of root transparency on segment shifting was significant for both the diacritic-plus-letter vowel morphological patterns and for the diacritic-plus-letter consonant patterns and did not differ statistically between the two. The vowel-only (i.e., diacritic-plus-letter) word pattern entailed the addition of a letter in the word-final position, but it also required the infixation of a vowel letter between the consonants of the root. This letter disrupted the orthographic coherence of the consonant sequence that defined the root. Nevertheless, a distinction was still observed between transparent and opaque roots with vowel diacritic-plus-vowel letter patterns. This finding suggests that orthographic integrity of the root does not play a role in the present task.

Significant effects for the letter–consonant pattern are particularly informative. This pattern always included a consonant and vowel in the initial position so that, in principle, articulation of the initial syllable could have commenced before the morphological status of the pattern had been determined. That is, the source words as well as the targets for /ma-ε-εt/ patterns all had /ma/ as the initial syllable. Nevertheless, the word patterns were shifted to a new target string more rapidly when the embedded roots were transparent than when they were opaque. This outcome suggests that in this task, the morphological word pattern is treated as one entity despite its distribution throughout the word. That is, the segment shifting measure is not sensitive to the sequential characteristics of the morphological pattern that must be moved.

General Discussion

The results of the present study replicate those reported previously in Serbo-Croatian (Feldman, 1991, 1994). That is, morphological affixes were shifted faster than their nonmorphological but phonologically matched controls. The facility with which morphological segments relative to their controls can be manipulated is consistent with the misorderings of morphological segments that occur in spontaneous speech productions (Fromkin, 1973). Specifically, morphological segments are more vulnerable to misorderings than are phonologically matched but nonmorphemic segments (Garrett, 1980, 1982; Stemberger, 1984). In Experiments 1 and 2, letter sequences that were morphemic in status were shifted more rapidly to real-word and to pseudoword targets than were their controls. In Experiments 3 and 4, the experimental manipulation was one of morphological transparency, and all segments were shifted to pseudoroot targets. Word patterns from source words with transparent roots were shifted faster than patterns from opaque roots. Despite methodological differences, the same pattern of results was replicated in four experiments. The fact that similar effects were observed for pseudoword targets and for real-word targets is consistent with the absence of word class compatibility results between source and target words in Serbo-Croatian (described above) and is relevant to the locus of the effect (Feldman, 1991, 1994). It suggests that the outcome in the segment shifting task does not depend on morphological compatibility (in the morphologically complex condition but not in the morphologically simple condition) between source word and target. By implication, the effect cannot reflect a special relation between what participants produced and the morphologically complex source word they viewed (e.g., BRIGHTEN and HARDEN), otherwise, again, it should have been absent for pseudoword targets. Because both meaningful and meaningless utterances in English showed a similar effect of morphology in the present task, the effect is unlikely to reflect lexical editing at output or other late processes. Finally, because the effect could not be linked to the lexicality of the output or to the relation between source and target items, accounts that emphasize the semantic characteristics of the morphologically complex items or of morphemes in general are invalidated.

Although the presentation format varied slightly across languages so that comparisons must be interpreted with caution, it was the case that similar results were observed with materials constrained by the concatenative morphology of English and by the nonconcatenative morphology of Hebrew. In concatenative morphologies such as English and Serbo-Croatian, a morphological affix typically appears in word-final (or sometimes in word-initial) position,[12] and the morphological status of a letter sequence typically depends on the word in which it occurs. The experimental manipulation of morphology with English materials focused on shifting letter sequences that varied with respect to morphological status. Importantly, the effect occurred whether or not a word was embedded inside the source word. Moreover, its magnitude was linked with a preliminary measure of affix reliability. In the nonconcatenative language of Hebrew, a word is composed of a sequence of (usually) three consonants that define a root and a word pattern that is phonologically and sometimes orthographically intercalated between those consonants. Word patterns disrupt the phonological integrity of the root, whereas the effect on orthographic integrity depends on whether the vowels are written with optional diacritics or with letters (and on whether the pattern also includes consonants). When segmentation and shifting of the Hebrew word pattern disrupted the orthographic pattern by removing letters and diacritics from the source word and adding them to the target (Experiment 4), results were enhanced relative to when the orthographic pattern of the root and the target was preserved (Experiment 3). By most accounts, word patterns are always morphemic. Therefore, the exact manipulation used in the segment shifting studies with English and Serbo-Croatian materials was not possible in Hebrew. Instead, the morphological manipulation was defined in relation to the root with which the word pattern combined. Specifically, if the root appeared with other word patterns (i.e., was polygamous), then the root was morphologically transparent. If the root appeared exclusively with a particular word pattern (i.e., was monogamous), then it was morphologically opaque. That is, the morphological manipulation focused on the transparency of the root. An analog of transparent and opaque base morphemes to which English

[12] Because several affixes can be appended to the same base in English, an affix can also occur in positions that are not word final.

speakers can naturally relate occurs in the BUDS–SUDS pair. Note that the former is transparent in that both BUD and S appear in other formations, whereas SUD, the "root" of the latter, appears only in this form. SUDS-type constructions are typical of the control words in the Hebrew experiments. (The anticipated outcome of the English analog would be faster shifting latencies for S from BUDS than from SUDS.)

The segment shifting result appears not to be sensitive to the familiarity of a source word's orthographic pattern. In English, morphologically complex source words tended to be lower in surface frequency than morphologically simple source words. In Hebrew, morphologically transparent source words tended to be higher in frequency (as assessed by both subjective frequency and lexical decision times) than opaque source words. Post hoc analyses within each language indicated that results with the segment shifting task could not directly be linked to surface frequency of the source word. Also, it is important to reiterate that the outcome in the segment shifting task was not linked to either the position of the shifted letter sequence in a word or to its integrity as a unit. Similar results were observed when the shifted segment preserved the orthographic integrity of the target root (as is typical of morphological processes in English) and when the segment disrupted it (as can occur in Hebrew). Collectively, results across all four experiments indicate that the segment shifting task is sensitive to the morphological components of the source word and their tendency to combine with other morphemes. It is not sensitive to source word (surface or cumulative) frequency nor to lexical properties of the target.

Accounts that are based on sequential probabilities between letters are not plausible even in English because the composition of morphemic and nonmorphemic sequences was well matched in this study (see also Rapp, 1992). Segment shifting effects in nonconcatenative languages such as Hebrew are also not amenable to a sequential account of either letter or morpheme units because, as elaborated above, two morphological patterns are mixed within the word, and thus they do not form units. If units are defined phonologically, morphological units lack coherence because the vowels of the word pattern are infixed between the consonants of the root. If units are defined orthographically, morphological units are coherent in Experiment 3 but lack coherence in Experiment 4, in which the word pattern also included letters (vowels or consonants) that disrupted the sequence of consonant letters that formed the root. In essence, morphemes need not be orthographically defined units to produce effects in the segment shifting task. Because morphemes do not form orthographic segments in a nonconcatenative morphology, it is implausible that the observed effects arose independently of lexical knowledge.

In summary, the segment shifting task demands segmentation of source words. A match between the (experimentally induced) components of the source word and the components of that word specified lexically appears to facilitate performance. For morphologically simple (and monogamous) source words, segmentation and affixation of the final sequence of letters is difficult because it is linguistically arbitrary. For morphologically complex (and polygamous) source words, by contrast, segmentation and affixation is relatively easy because it is principled and may depend on units made more salient by their tendency to combine to form many different words.

Although it is evident that lexical knowledge is required to make the morphological structure of a word available in Hebrew, two accounts are plausible. One option is that priority is granted to the root and that the word pattern can only be determined once the root has been identified. Alternatively, it is possible that first the word pattern must be extracted from the source word. Admittedly, the two options described comprise a very fine distinction and assume serial processes, and the present results cannot unequivocally specify how the component morphological structure becomes available in Hebrew. Nevertheless, several studies have suggested that the root serves as a lexical unit in Hebrew, so it seems plausible that root extraction figures prominently in linguistic processing for the Hebrew speaker (see Bentin & Frost, 1995; Frost & Bentin, 1992, for a review). By this account, properties of the root should influence the pattern of results, and this hypothesis deserves further investigation.

Reliability effects of the affix in English and transparency effects of the root in Hebrew are both compatible with an account that emphasizes lexical representations that specify morphemic components and rules for their combination. As generally defined, some affixes tend to be broader in scope so that many new words can be formed by combining them with other morphemes. Inflectional affixes tend to be more broad in scope than derivational affixes, so it is interesting that in Serbo-Croatian, inflectional affixes produced more stable results in this task than did derivational affixes (Feldman, 1994). The affixes in Experiments 1 and 2 showed a significant relation between reliability of the segment as a morpheme and segment shifting latency. The observation from Hebrew that morphemic word patterns could be shifted from transparent roots more rapidly than from opaque roots extends this result by showing that transparency of the root is also relevant.

Smith (1988) proposed that morphological transparency influences how morphologically complex words are processed so that the structure of words whose base morphemes are words (e.g., TEST in PROTEST) is more accessible than that of words whose base morphemes are never words (e.g., LUSION in ILLUSION). In addition to semantic compositionality (e.g., Marslen-Wilson et al., 1994), a factor that may contribute to transparency is the frequency with which a particular morpheme enters into combinations with other morphemes or, in Hebrew, with other word patterns. This is the core of the transparency manipulation used in Experiments 3 and 4 and is similar in spirit to several recent proposals (e.g., Taft & Zhu, 1995). In effect, segmentation as required to perform the segment shifting task may be facilitated when the morphemic components appear as morphemes in many different words.

Studies of word recognition are generally based on languages with concatenative structures in which morphemes are typically coextensive with syllabic units and those units are linearly concatenated. It is frequently assumed that the morphemes of a word are processed in a serial fashion (Hudson, 1990) or that the morpheme can be represented in terms of orthographic structure (Chialant & Caramazza, 1995). The disruption manipulation in Hebrew as well as analogous outcomes with concatenative and nonconcatenative materials generally shows that the specialness of the morpheme is based on neither its orthographic nor its phonological integrity. Comparable results when segmenting final letter sequences from stationary portions that varied in morphological status in English and when segmenting word patterns from transparent or opaque roots in Hebrew indicate that whether morphemic structure is concatenative or nonconcatenative, shifted segments are not treated in isolation from the lexicon. Lexical knowledge must include a word's morphological structure.

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