*Factors Affecting Stress Placement for English Nonwords include Syllabic Structure, Lexical Class, and Stress Patterns of Phonologically Similar Words**

Susan G. Guion[1], **J.J. Clark**[1], **Tetsuo Harada**[1], **and Ratree P. Wayland**[2]

[1] *University of Oregon*
[2] *University of Florida at Gainesville*

Key words

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lexical class

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syllable structure

word stress

Abstract

Seventeen native English speakers participated in an investigation of language users' knowledge of English main stress patterns. First, they produced 40 two-syllable nonwords of varying syllabic structure as nouns and verbs. Second, they indicated their preference for first or second syllable stress of the same words in a perception task. Finally, they indicated words they considered to be phonologically similar to the nonwords. Analyses of variance on the production and perception data indicated that both syllabic structure and lexical class (noun or verb) had an effect on main stress assignment. In logistic regression analyses on the production and perception responses, predictions of stress placement made by (1) syllable structure, (2) lexical class, and (3) stress patterns of phonologically similar words all contributed significantly and uniquely to the prediction of main stress assignment. The results indicate that phonological theories of English word stress need to allow for multiple, competing, probabilistic factors in accounts of main stress placement including syllabic structure (most notably vowel length), lexical class, and stress patterns of phonologically similar words.

1 Introduction

This paper presents the results of experimental studies of speech production and perception designed to further our understanding of the factors influencing main stress placement in native English speakers. The effects of three factors on stress placement

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Address for correspondence. Susan G. Guion, Department of Linguistics, 1290 University of Oregon, Eugene, OR 97403-1290; e-mail: <guion@uoregon.edu>.

in two-syllable nonwords were investigated: syllabic structure, lexical class (noun vs. verb) and stress pattern of phonologically similar words. All three factors are found to have significant and unique effects on main stress placement in nonwords. The implications of these findings for phonological theories of stress will be discussed.

1.1
The potential factors to be investigated

Syllabic Structure. The first potential factor to be considered is syllabic structure. Distributional descriptions of English stress patterns suggest that the structure of syllables within a word affects stress placement for that word. A standard analysis of English predicts stress based on vowel length and number of coda consonants (see, e.g., Chomsky & Halle, 1968; Hayes, 1982). In the case of two-syllable nouns and verbs, the objects of investigation in the current study, stress regularly adheres to the following patterns. For two-syllable verbs, the final (ultimate) syllable will receive main stress if it has a long vowel or ends in at least two consonants. In this case, the first (penultimate) syllable may have secondary stress, contain an unstressed full vowel, or contain a reduced vowel.[1] See examples in (1). If the ultimate syllable does not have a long vowel or end in two or more consonants, the penultimate syllable is stressed. See examples in (2).

1. atone [ə'tʰoʊn]; obey [ˌou'beɪ] or [o'beɪ] or [ə'beɪ]; divine [də'vaɪn]; usurp [ˌjuː'sɝ p] or [juː'sɝːp]; collapse [kə'læps]; elect [ˌiː'lɛkt] or [ɪ'lɛkt] or [ə'lɛkt]

2. edit ['ɛdɪt]; cancel ['kʰænsl̩]; promise ['pɹ̥ɑmɪs]

For two-syllable nouns, the ultimate syllable will receive main stress only if it has a long vowel.[2] Otherwise, the penultimate syllable will have the main stress. In this case, the ultimate syllable may have secondary stress, full vowel with no stress, a reduced vowel, or a syllabic consonant. See examples in (3) and (4).

3. monsoon [ˌmɑn'suːn] or [mɑn'suːn]; machine [mə'ʃiːn]; canoe [kə'nuː]

4. barrel ['bæɹl̩]; insect ['ɪnˌsɛkt] or ['ɪnsɛkt]; sister ['sɪstɚ]; subject ['sʌbˌdʒɛkt] or ['sʌbdʒɛkt] or ['sʌbdʒəkt]; apron ['eɪpɹən]; parsnip ['pʰɑːɹˌsnɪp] or ['pʰɑːɹsnɪp]

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1 The status of the nontonic syllable in cases where the vowel is not reduced is problematic. It is difficult to perceptually determine whether the vowel has secondary stress or is stressless (see, e.g., Burzio, 1994, p. 48). Articulatory distinctions are also difficult to make: Stone (1981) found only one level of stress based on jaw movement between most prominently stressed and reduced syllables. Whether nontonic syllables with full vowels are perceived to have secondary stress or be stressless also seems to vary with speaking rate and style. However, the focus of this study is on the placement of main stress and, as such, the status of the nontonic syllables is left as an open question. The transcriptions of the example words provided here reflect the stress levels of the nontonic syllables considered possible by the authors.

2 See Burzio (1994, pp. 48–52) for an alternative to the standard view. Note that there are many nouns with a final long vowel that nonetheless have penultimate stress (e.g., protein ['pɹ̥oʊtiːn]).

In further consideration of the potential effect of syllabic structure on stress placement, some major elements of stress typology will briefly be considered here. Cross-linguistically, it is common for stress placement to be determined by foot structure and for words to be footed and stressed in either a right-to-left or left-to-right manner with main stress falling on either the first or last foot in the word. The nature of the feet used may vary from language to language and can either be sensitive or insensitive to syllable weight. (i.e., length of vowel and number of coda consonants). Most languages have feet that are sensitive to syllable weight. English is considered to be such a quantity sensitive language.

In a discussion of syllable weight typology, Blevins (1995) notes that syllables treated as light by a language most often have an optional onset consonant and only a vowel in the rime (C_0V). On the other hand, syllables treated as heavy by languages most often have a long vowel (C_0VV) or a coda consonant (C_0VC). However, some languages, such as Huasteco and Hawaiian, treat syllables closed by a single consonant (C_0VC) as light and only syllables with a long vowel (C_0VV) as heavy. There are no apparent attestations of the reverse pattern (i.e., C_0VV light and C_0VC heavy). Another typological finding on the effect of coda consonant on syllable weight is that some languages treat syllables with two coda consonants (C_0VCC) as heavier than syllables with one coda consonant (C_0VC). Hayes (1995) mentions Hindi (p. 162 ff.) and Estonian (p. 316 ff.) as examples of such languages. This relative weighting of double and single coda consonants is rare in the world's languages, most likely due to the rarity of coda consonant clusters, especially in nonfinal position (see, e.g., Blevins, 1995).

Interestingly, some languages that are thought to have feet demonstrate a pattern of stress placement in which certain syllable types are given special prominence and are preferentially stressed. In other words, a prominent syllable will receive main stress even in cases where it does not conform to the regular metrical pattern. Commonly, prominent syllables are those with long vowels, low vowels, high tones, or sonorant codas (Hayes, 1995, pp. 270–276). In other words, stress falls on the prominent syllable even when stress may not be predicted by foot structure. A classic example comes from Klamath, a language spoken in Oregon (Barker, 1964). In Klamath, the rightmost long vowel must be stressed. Otherwise, stress follows a regular default pattern. Even though Klamath does allow coda consonants, closed syllables are not considered prominent; only syllables with long vowels are considered prominent. It is noteworthy that Hayes' survey does not mention any language in which a coda consonant, but not a long vowel, creates a prominent syllable.

Other languages are not usually analyzed as having alternating foot structure and are considered to have unbounded stress systems. These languages assign stress only to certain syllable types while not seeming to rely on a metrical structure. It is common for such languages to stress only syllables with long vowels. Hayes (1995, pp. 296–297) gives many examples of unbounded systems that have special prominence for long vowels including Mayan, Altaic, and Tibetan languages.

Given the distributional descriptions of English main stress and the typological evidence indicating that heavy syllables tend to attract stress, it seems likely that syllable structure will have an effect on main stress placement in nonwords for English speakers such that heavy syllables will be stressed more often than light syllables. In addition, the typological observation that syllables with long vowels may attract main stress even if syllables with short vowels and coda consonants do not (but not vice versa) suggests that long vowels may be greater attractors of main stress than coda consonants are. Finally, the typological observation that two coda consonants can create a heavier syllable than one coda consonant suggests that the number of coda consonants may also play a role in stress placement.

Lexical Class. Another potential factor affecting stress placement is lexical class. Here the lexical classes of nouns and verbs are considered. It has long been noted that bisyllabic nouns are more likely to have main stress on the first syllable than bisyllabic verbs (Chomsky Halle, 1968; Liberman & Prince, 1977; Sherman, 1975).[3] More recently, empirical studies have further confirmed these observations. Sereno (1986) and Kelly and Bock (1988) investigated the asymmetrical stress distribution for nouns and verbs by collecting the dictionary stress assignment of bisyllabic nouns and verbs listed in the Francis and Kučera (1982) word frequency norms. Considering only "pure" nouns and verbs, that is, words that did not have homographs in other lexical classes, Sereno (1986) found that bisyllabic pure nouns are stressed on the first syllable 76% of the time, whereas bisyllabic pure verbs are only stressed on the first syllable 34% of the time. Similarly, Kelly and Bock (1988) found that of the pure nouns, 94% were stressed on the first syllable and of the pure verbs, only 31% had stress on the first syllable.

Sereno and Jongman (1995) recently investigated the effect of grammatical category on stress production in categorically ambiguous bisyllabic words (e.g., *answer*, *design*). They found that there were slight but consistent differences in the production of these ambiguous words when they were produced as nouns or as verbs: Nouns tended to have more characteristics of stress on the first syllable. (Note that the words were all produced in the same sentence frame. The noun and verb productions were conditioned by the use of noun and verb production blocks.) Thus, the noun-verb asymmetry in stress placement seems to be a strong effect permeating the English lexicon and affecting even words conventionally considered as noun-verb homophones.

Phonological Similarity. The third factor considered here derives partially from the results of previous empirical studies (e.g., Baker & Smith, 1976, to be discussed more fully below) in which stress patterns of real words were found to be predictive of stress placement on phonologically similar nonwords. It seems that the stress patterns of known words may play a role in the stress assignment on new words. Studies of machine learning have also demonstrated that the stress patterns of the nearest phonological neighbors can accurately predict the stress of the novel words: Using exemplar-based models, Daelemans, Gillis, and Durieux (1994) and Gillis, Daelemans, and Durieux (2000) have demonstrated that a learning algorithm based on similarity of new items to stored exemplars exhibits the same behavior found in human language learners and users. Namely, an exemplar-based similarity algorithm can generalize stress patterns beyond the data on which it was trained and assign stress to new words in a manner similar to that found for language learners.

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[3] Indeed, many proposals of English stress rules have had to treat nouns and verbs differently. Either different rules apply to them (Chomsky & Halle, 1968), or different units are extrametrical (Hayes, 1995), or one lexical class is marked to not undergo certain rules (Halle, 1998).

1.2
Previous studies on factors affecting stress placement

After the publication of *The Sound Pattern of English* (Chomsky & Halle, 1968, henceforth SPE) researchers conducted experiments to determine whether or not the stress rules proposed in SPE were active in stress placement. Typically, these tests involved investigation into the stress assignment of novel words. The assumption was that if stress rules productively assign stress to lexical entries during the course of the derivation, then they should also apply to novel forms. Despite the many studies, no clear results emerged from this line of investigation.

Several experiments reported no effects of English stress rules. Walch (1972) presented nonwords to three native English speakers in written paragraphs and collected their productions. Participants did not show evidence of rule application in their productions. However, in a perception task, the same subjects fared better at determining whether or not stress placement was correct according to the rules. Baptista (1984) presented nonwords orthographically to 30 native English speakers. They were asked to read the words in sentences and stress was transcribed. Baptista found that most of the rules outlined in SPE were not reliably followed.

However, some studies have reported results of stress assignment on nonwords consistent with predictions made by the SPE stress rules. In an early experiment, Ladefoged and Fromkin (1968) gave linguistics students written sentences containing nonwords and asked them to transcribe their pronunciation of the nonwords. There was a fair amount of agreement among the 24 participants as to the stress assignments and transcriptions. The stress placements themselves were consistent in many cases with the predictions of SPE rules. Trammell (1978) presented unknown English words of Greek, Latin and Germanic origins to 20 native English participants in sentence contexts. The participants read the sentence to themselves and then said the target word out loud. The stress placements were largely predicted by SPE rules.

In a study investigating multiple factors, Baker and Smith (1976) investigated the predictions of the SPE stress rules and the prediction that stress patterns would be assigned on the basis of particular, real English words. Nonwords subjectively judged to be similar to real words were designed so that the stress predicted by the SPE rules would sometimes agree with that of the similar word and disagree with it at other times.[4] Sixteen native English speakers read the words in context sentences. The results indicated a complex relationship between rule governed and analogical stress patterns, which also interacted with lexical class. They found that stress assignment based on analogy with a similar word predicted stress in many cases, even when the prediction went against the rules. Specifically, analogical predictions won over rule-based predictions for cases in which analogical stress predicted first syllable stress on nouns or second syllable stress on verbs. While analogical effects were seen for all word lengths, longer words were more likely to receive the stress of phonologically similar words.

Most of the studies just reported have design aspects that make interpretation of

4 For example the nonwords *estonish* and *astonize* were derived from *astonish.* The former preserved the syllable structure and, hence, the predicted stress placement, whereas the latter did not.

their results difficult. First, the prosodic context in which the words were elicited was not held constant. Kelly and Bock (1988) have demonstrated that prosodic context influences stress placement in bisyllabic nonwords: Words (both nouns and verbs) were more likely to have first syllable stress when they followed an unstressed syllable and preceded a stressed syllable than when they followed a stressed syllable and preceded an unstressed syllable. Another problem lies in the mode of presentation. Orthographic presentation of the stimuli may suffer from uncontrolled literacy and reading effects. Baptista (1984, p. 221) found that "English orthography proved to be ambiguous, many segments being interpreted in several different ways. At times, because of different interpretations of the segments to be pronounced, the nonsense word no longer satisfied the conditions for the stress rule to be applied." Indeed, most of the studies summarized here report that much of their data had to be discarded due to different readings of the same English orthography.

1.3 *The current study*

The research reported here was designed to determine the effects of three factors on the placement of main stress. The predictive power of stress rules proposed in the phonological literature will not be tested. It is understood, however, that some of the factors investigated may underlie proposals made for models of stress placement. Here, three basic factors (i.e., syllable structure, lexical class, and stress patterns of phonologically similar words) with potential influence on stress placement (as described above) will be investigated. After discussing the results from this study, the implications for phonological models will be considered.

Briefly outlining the experimental protocol used here, two-syllable nonwords were aurally presented as isolated, stressed syllables to native English speakers who were instructed to produce them in a noun or verb frame. Perception data was gathered on the preferred stress of the same words produced with first and second syllable stress as nouns and as verbs. Real words considered to be phonologically similar to the nonwords were also solicited from the participants.

The design of the current study avoids many of the problems encountered by previous studies. First, the prosodic context for production of target words is held constant across trials by eliciting the words in a sentence context in which they were always preceded by schwa. Second, stimuli are presented aurally (as isolated, stressed syllables) to avoid problems with the interpretation of English orthography. In addition, this study adds a perceptual assessment of stress placement found in very few previous studies. Another novel feature of this study is the collection of phonologically similar words from each participant individually. This allowed for a more exacting determination of the similarity between nonwords and real words for each individual than previous approaches in which similarity was determined based on arbitrary aspects of phonological form and equal similarity for all participants was assumed.

The two syllable nonwords used as stimuli in the current study have four different types of syllabic structure. Type 1 has a long (i.e., tense or diphthongized) vowel with no coda in the first syllable and a short vowel with a complex coda in the second syllable (CVV.CVCC, e.g., [beɪ.tɪst]). Type 2 has a short vowel with no coda in the first syllable and a short vowel with a complex coda in the second syllable (CV.CVCC, e.g., [dɛ.kɪps]).

Type 3 has a short vowel with no coda in the first syllable and a short vowel followed by one consonant in the second syllable (CV.CVC, e.g., [nɪ.lɛt]). Finally, Type 4 has a short vowel with no coda in the first syllable and a long vowel followed by one consonant in the second syllable (CV.CVVC, e.g., [kɪ.giːn]).

Based on the distributional facts of English and the cross-linguistic propensity for long vowels and perhaps to a lesser extent, coda consonants, to attract main stress, the syllabic structure of the test words is predicted to affect stress placement in the following ways: Words of otherwise similar structure but differing in vowel length in one of their syllables should receive comparatively more main stress on the syllable with the long vowel. Words of otherwise similar structure but differing in number of coda consonants in a final syllable should receive comparatively more main stress on the syllable with more coda consonants. (See, e.g., the distributional facts for English verbs presented above). Thus, the effect of long vowels predicted the following differences: Type 1 (CVVCVCC) should have more first syllable stress than Type 2 (CVCVCC). Likewise Type 3 (CVCVC) should have more first syllable stress than Type 4 (CVCVVC). The effect of final coda consonants predicted the following difference: Type 3 (CVCVC) should have more first syllable stress than Type 2 (CVCVCC). The potentially greater effect of long vowels than coda consonants on stress placement would also predict that Type 2 (CVCVCC) would have more first syllable stress than Type 4 (CVCVVC).

The lexical class factor predicts that nouns will receive main stress on the first syllable more often than verbs and that verbs will receive main stress on the final syllable more often than nouns. Finally, the phonological similarity factor predicts that the stress patterns on the phonologically similar words collected from the participants will predict stress placement on the relevant nonwords.

The independence of these factors is assessed in a regression analysis. Each factor found to make a significant, unique contribution can be interpreted as (at least partially) unconfounded with the other factors. If, for example, the phonological similarity factor were found to influence stress placement independently of the other two factors, this would indicate that the dimensions of phonological similarity were not those of syllable structure or lexical class in at least some cases. In other words, the phonological similarity effect could significantly predict word stress even when the similar word was of a different syllable structure and lexical class from the nonword.

2 Method

Before giving the details of the method, a brief summary is provided here. Seventeen native speakers of English participated in three tasks. First, in the Production Task, participants were asked to produce two syllable nonwords in both noun and verb sentence frames. Each syllable of the word was presented in isolation and the participant produced a stress pattern as they concatenated the syllables into a word and said it in a sentence frame in an on-line task. Second, in the stress preference Perception Task, the participants heard the same nonwords produced in a sentence frame as nouns and verbs with either first or last syllable stress. They responded whether they preferred the sentence with first or last syllable stress on the nonword. Third, in the Word Similarity Task, the participants listened to the same words presented as isolated syllables. This time the words were not presented in a sentential context. The participants had 10 seconds to say any phonologically similar words they thought of.

2.1
Participants

The same 17 American English speakers (7 males, 10 females) were paid to participate in all three tasks. Participants ranged in age from 18 to 54 years with a mean of 24 years. None reported being diagnosed with any language or reading disorders and all passed a pure tone hearing screening from 500 to 4000 Hz at octave intervals (16 at 25 dB and 1 at 30 dB). All learned English as a native language and no other language was spoken in the home during childhood. The participants had some history of foreign language study in high school and/or college but none had lived abroad for more than four months at a time.

2.2
Production Task

The purpose of this task was to investigate the factors contributing to stress assignment in the production of nonwords. Of interest was whether the syllabic structure of the words would influence stress placement. On the basis of the above considerations, long vowels were expected to be the greatest attractors of stress, followed by coda consonants. In addition, the prediction that nouns would be assigned more first syllable stress than verbs regardless of syllable structure was investigated.

Materials. Four two-syllable word types were used. There were 10 tokens of each syllabic type. Table 1 lists the words used.[5] The syllables composing the 40 words listed in Table 1 were recorded on DAT tape with a high quality microphone by a single speaker in the frame "Now I say ___." Thus each syllable was produced with pitch accent and stress. The productions were digitized at 22.05 kHz (16 bit) on a personal computer. The syllables were then excised from the carrier phrase and normalized to 50% peak intensity. The same speaker also recorded the phrases "I'd like to" and "I'd like a". The final "to" and "a" were produced in a reduced form (i.e., [tə] and [ə]). These phrases were also digitized and normalized. The phrase "I'd like to __" will be referred to as the verb frame and the phrase "I'd like a __" will be referred to as the noun frame.

Procedure. Participants were asked to concatenate the isolated, stressed syllables into a single word and say it in a carrier phrase. Each of the syllable pairs was presented twice,

5 While some of the word endings are phonologically consistent with both monomorphemic and bimorphemic words (i.e., words having an inflectional or derivational suffix), we find it unlikely that the words were perceived as suffixed by the participants. This is based on three pieces of evidence. First, pilot testing involving extensive debriefing revealed no such interpretation. Second, the sentence frames in which the words were produced were consistent with stem forms (single nouns and verb stems). Third, the phonologically similar words collected in the Word Similarity Task (see the Appendix) were overwhelmingly unsuffixed (over 85%).

TABLE 1

The nonwords used in the three tasks

Type 1	*Type 2*	*Type 3*	*Type 4*
CVV CVCC	CV CVCC	CV CVC	CV CVVC
beɪ tɪst	dɛ kɪps	nɪ lɛt	nɪ liːt
tuː kɪps	nɪ gɛpt	dɛ sɪn	dɛ guːt
taɪ gɛpt	kɪ mɪnz	sɛ lɪn	bɪ teɪs
poʊ tɪst	sɛ tɪst	bɪ tɛs	bɪ toʊs
giː kɪps	bɪ bɛkt	sɛ gɛt	kɪ giːn
poʊ bɛkt	sɛ bɛkt	dɛ lɛt	sɛ liːt
tuː mɪnz	dɛ mɪnz	nɪ sɪn	nɪ guːt
taɪ mɪnz	nɪ kɪps	kɪ gɛt	kɪ teɪs
beɪ bɛkt	kɪ gɛpt	bɪ lɪn	dɛ toʊs
giː gɛpt	bɪ tɪst	kɪ tɛs	sɛ giːn

once with the noun frame and once with the verb frame. Two pseudorandomized, counterbalanced blocks were used, making a total of 80 trials. Each syllable pair was presented only once in each block. Half of the productions in each block were nouns, half verbs. There was a short distractor task between the two blocks. Participants were given some practice trials using nontest words before the first block.

Stimulus presentation was controlled by software (SPARCS, developed by Steve Smith, University of Alabama at Birmingham, Department of Rehabilitation Sciences) on a personal computer and played over high quality loud speakers in a sound attenuated room. Participants adjusted the presentation volume to a comfortable level before testing began. The participants wore a head mounted microphone and their answers were recorded on DAT tape. For each trial, the participants were first presented with a frame sentence. Presentation of the frame was both aural and visual. After a 500ms delay, two stressed, isolated syllables were presented with a 500ms interstimulus interval. Presentation of these target syllables was aural only; no orthographic representation was given. Participants could replay the trial if they wished. After responding, they pushed a button to continue to the next trial.

The participants were instructed to take the two syllables, keep them in the same order, and make a single word from them. They were instructed to keep all the sounds they heard in the word they said. Additionally, participants were asked to say the word in the carrier phrase that had just been presented. They were asked to say the carrier phrase in the same way they had heard it. If the final word in the frame ('to' or 'a') was produced with stress during the practice block, the participant was stopped and corrected. All participants could easily produce the carrier phrase in the desired manner. It was important that all the words were produced in the same metrical frame because of potential confounding effects of the frame on stress placement. The participants were also told to take their time and consider all possible responses.

Coding and reliability. The first author (SGG, a native American English speaker) listened to the taped responses and coded them as having main stress on either the first or second syllable. Some of the words were produced with segmental content different from that in the stimulus. If the substitution did not change the syllable structure (e.g., [veɪbɛkt] for [beɪbɛkt]), the response was counted. However, if the substitution did change the syllable structure (e.g., [bɛbɛkt] for [beɪbɛkt]), the response was counted as missing. Out of the 1,360 responses 18 responses (1%) were discarded because they did not reproduce the syllable pattern presented to the participant.

Rater reliability was assessed by recoding a subset of the data. Ten responses were arbitrarily chosen from each of 11 randomly picked participants (for a total of 110 items). These responses were digitized and removed from their sentential context. The first author as well as the second author (JJC, also a native American English speaker) blindly recoded these responses. The intraclass correlation coefficient (McGraw & Wong, 1996) for the two ratings done by SGG was quite high ($\rho = .92, p < .001$). This indicates that the rater coded stress placement with a high degree of reliability. When the first rating by SGG and the rating by JJC were submitted to a single measure intraclass correlation (which indicates the reliability when a single rater is used, as was the case here), the correlation coefficient was high ($\rho = .90, p < .001$), indicating that the use of one rater was highly reliable.

2.3
Perception Task

The purpose of this experiment was to investigate the factors contributing to stress preference in the perception of nonwords. As in the Production Task, the roles of the factors of lexical class and syllable structure were investigated.

Materials. The 40 words listed in Table 1 were produced with main stress on the first and second syllable in each of the carrier frames "I'd like a __" and "I'd like to __" making a total of 160 sentences. The 'a' and 'to' of each phrase was produced in a reduced manner. The same talker used in the Production Task, a trained phonetician, produced these sentences. With the goal of obtaining naturally and consistently produced sentences, a block elicitation method was used which allowed the speaker to maintain a rhythmic pattern. First, all of the words were recorded in the noun frame with first syllable stress. The list of words was said three times in this fashion. After a rest period, all of the words were recorded in the noun phrase with final stress. After a break, the procedure was repeated for the verbs. The productions were recorded on DAT tape. The sentences from the third repetition of each of the four blocks were used to make the stimuli. The recordings were digitized at 22.05 kHz (16 bit) on a personal computer. Each phrase was edited into its own file. These files were then normalized to 50% peak intensity.

Procedure. Participants were asked to listen to the prerecorded phrases in pairs. They were instructed to listen to the two sentences and indicate which one sounded the most like a real English sentence to them. In a given trial the same sentence frame (noun or verb) was presented. The main stress of the target word was all that varied; it was either on the first or the last syllable. For example, consider the trials for two representative words in (5) and (6).

5. **Trials for [**beɪbekt**]**

I'd like a 'beɪbɛkt (pause)
I'd like a beɪ'bɛkt

I'd like to 'beɪbɛkt (pause)
I'd like to beɪ'bɛkt

6. **Trials for [**bɪlɪn**]**

I'd like a bɪ'lɪn (pause)
I'd like a 'bɪlɪn

I'd like to bɪ'lɪn (pause)
I'd like to 'bɪlɪn

Each target word was presented in two trials, once as a noun and once as a verb. Two pseudorandomized, counterbalanced blocks were used, making a total of 80 trials. Each word was presented only once in each block. Half of the productions in each block were nouns, half verbs. The order of first or second syllable stress within a trial was also controlled. For a given word, the order of stress presentation remained constant for both the noun and verb trials. For each of the four word types, five of the words were presented with initial stress then final stress. Conversely, the other five were presented with final stress then initial stress. There was a break of a few minutes between the two blocks. Participants were given some practice trials using nontest words before the first block.

Stimulus presentation was controlled by software (SPARCS, developed by Steve Smith, University of Alabama at Birmingham, Department of Rehabilitation Sciences) on a personal computer and played over high quality headphones in a sound attenuated room. Participants adjusted the presentation volume to a comfortable level before testing began. For each trial, the participants were presented two sentences with a 1500ms interstimulus interval. They responded by indicating which sentence they preferred by pushing a button labeled 'first' or 'second'. This brought up the next trial after a 2000ms delay. No repetition of the trial was allowed.

2.4
Word Similarity Task

The purpose of this experiment was to gather information on main stress placement of words that were phonologically similar to the nonwords used in the study. Participants heard the same nonwords as in the previous two tasks, presented as isolated syllables. An interval followed the presentation in which time the participants listed any phonologically similar words they thought of.

Materials. The 40 words in Table 1, presented as two isolated, stressed syllables served as stimuli for this task. The recordings of the syllables from the Production Task were used.

Procedure. Participants were presented with two stressed syllables and asked: "Does the way they sound remind you of any real words?" They were told not to worry about the type or number of words they came up with and were asked to give information on any word they thought someone might not know (such as a personal or place name). At the end of the instructions they were reminded that we were interested in knowing which real words the syllables sounded like to them. It seemed that the participants were able to perform this task as most of their responses had obvious segmental commonalities with the stimuli (see the Appendix).

The words were presented in 40 trials in a single randomized block. Stimulus presentation was controlled by the same software used in the other tasks and played over high quality loud speakers at a comfortable listening level in a sound attenuated room. The participants wore a head mounted microphone and their answers were recorded on DAT tape. For each trial, two isolated syllables were presented with a 500ms inter-stimulus interval. No repetition of the trial was possible. There were 10 seconds between trials.

3 Results

The results of the study indicate that main stress placement in the production and perception of nonwords is affected by several factors. The syllabic structure of the words played a role: Specifically, syllables with long vowels were most likely to receive main stress. Evidence of coda consonant clusters attracting more main stress than singleton coda consonants was not found. Knowledge of main stress distribution based on lexical class (nouns are more likely to have first syllable stress than verbs) also had an effect on stress placement. In the data presented here, nouns were more likely to receive first syllable stress than verbs. Another factor found to affect main stress placement in nonwords was the placement of main stress in similar words (as assessed by the phonologically similar words that participants produced). In a regression analysis, the stress patterns of similar words acted as predictor of stress independently of the predictions made by syllable structure and distribution of stress across the lexical classes of noun and verb. The stress pattern of a similar word made a correct prediction about the observed stress placement on the nonwords even in cases where the observed placement differed from the predictions of the other two factors.

In this section, the results of the Production Task are presented first. An analysis investigating the effects of syllabic structure and lexical class on main stress production is detailed. Then the results of the Perception Task are presented. The effects of syllabic structure and lexical class on stress preference are investigated. Thirdly, a logistic regression analysis on the production data is presented in which the predictive power of syllable structure, lexical class and stress patterns of phonologically similar words is assessed. Finally a logistic regression analysis is performed on the perception data with the same predictor variables.

3.1 *Production Task*

The 40 nonwords presented in Table 1 were produced by the 17 participants, once in a noun frame and once in a verb frame. The productions were then coded as having main stress on the first or final syllable as described in the method section. For each nonword in each sentence frame, the number of first syllable stress responses was divided by the total number of responses for the 17 subjects, resulting in a proportion of first syllable stress responses for each word in each sentence frame. Because some of the scores were greater than .90 or less than .10, the proportions were arcsine transformed, producing scores that were normally distributed and had a constant variance (see, e.g., Woods, Fletcher, & Hughes, 1986, p. 220). The transformed scores were then submitted to a two-way analysis of variance (ANOVA).

The first factor, Syllabic Structure, had four levels. Type 1 (CVVCVCC) was predicted to have more first syllable stress than Type 2 (CVCVCC) due to the long vowel in the first syllable of Type 1. Likewise, Type 3 (CVCVC) was predicted to have more first syllable stress than Type 4 (CVCVVC) due to Type 4's final long vowel. It was also of interest to see whether Type 2 (CVCVCC) and 4 (CVCVVC) differed due to the different types of final super heavy syllables. Specifically, the long vowel in Type 4 was predicted to condition more final stress. Finally, Type 3 (CVCVC) was predicted to have more initial stress than Type 2 (CVCVCC) due to the final consonant cluster in Type 2.

The second factor was Lexical Class. The two levels were (1) words produced in the noun sentence frame and (2) words produced in the verb sentence frame. In two syllable words, nouns are more likely to have penultimate stress than verbs (Kelly & Bock, 1988). If statistical generalizations about the distribution of main stress placement among lexical items have an effect on the placement of stress in novel words, then this factor should have a significant effect and nouns should receive more first syllable stress than verbs independent of the syllabic structure.

First consider the mean proportion of first syllable stress for the four syllable types and two lexical classes displayed in Figure 1. Note that, in general, nouns were more often produced with first syllable stress than verbs. Also note that a long vowel in the first syllable conditioned more first syllable stress, whereas a long vowel in the final syllable conditioned more final stress.

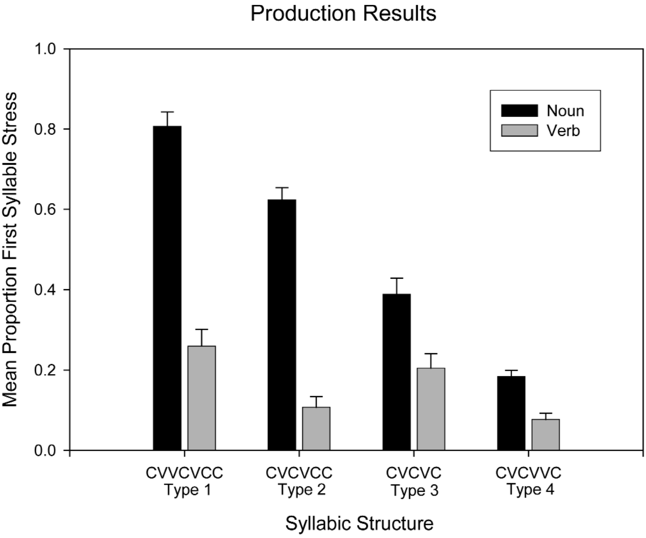

Figure 1

Mean proportions and standard errors of first syllable stress productions for four nonword types as produced by 17 native English speakers, in both noun (black bars) and verb (gray bars) sentence frames

The main effects of Syllabic Structure and Lexical Class were both significant, $F(3, 72) = 53.39, p < .001$ and $F(1, 72) = 203.87, p < .001$ respectively, as was the interaction, $F(3, 72) = 27.06, p < .001$. The interaction was explored by investigating the effect of Syllabic Structure on noun and verb productions separately and by investigating the effect of Lexical Class on each of the four word types.

The effect of Syllabic Structure was significant for nouns, $F(3, 36) = 58.62, p < .001$. Tukey's tests ($p < .01$) revealed that words of the structure CVVCVCC (Type 1) were more often stressed on the first syllable than CVCVCC (Type 2), which were in turn more often stressed on the penult than CVCVC (Type 3), which were more often stressed on the penult than CVCVVC (Type 4). The effect of Syllabic Structure was also significant for verbs, $F(3, 36) = 7.049$, $p = .001$. In this case, Tukey's tests ($p < .01$) found that words of the structure CVVCVCC (Type 1) were more often stressed on the first syllable than CVCVCC (Type 2) and CVCVVC (Type 4). In addition, CVCVC (Type 3) words were more often stressed on the first syllable than CVCVVC (Type 4) words. The trend for CVCVC (Type 3) words to have more first syllable stress than CVCVCC (Type 2) was not significant ($p = .16$).

The effect of Lexical class was significant ($p < .01$) for *all four* of the word types, $F(1, 18) = 83.19$, $F(1, 18) = 132.95$, $F(1, 18) = 11.47$, and $F(1, 18) = 11.75$, respectively, with nouns receiving more first syllable stress productions than verbs.

These results indicate that nouns are more often produced with main stress on the first syllable than verbs regardless of the syllable types involved. The effect of Syllabic Structure interacted with lexical class. Several of the predictions outlined for syllabic structure above were upheld in the case of nouns: Syllables with long vowels were more often stressed than syllables with short vowels in words of otherwise comparable syllable structure (i.e., Type 1 had more first syllable stress than Type 2 and Type 3 had more first syllable stress than Type 4). In addition, syllables made super heavy by a long vowel and singleton coda were more likely to be stressed than syllables made super heavy by a coda consonant cluster (i.e., Type 2 had more first syllable stress than Type 4). The prediction that syllables with short vowels and coda consonant clusters were more likely to be stressed than those with single coda consonants (i.e., Type 3 > Type 2) was not supported. A nonsignificant trend in this direction was observed for the verbs. However, a significant effect in the reverse direction was found for nouns (i.e., Type 2 had more first syllable stress than Type 3). In the case of verbs, the prediction that syllables with long vowels would more often be stressed than syllables with short vowels in words of otherwise comparable syllable structure was the only prediction to be upheld (i.e., Type 1 had more first syllable stress than Type 2 and Type 3 had more first syllable stress than Type 4).

3.2
Perception Task

The same 40 nonwords (presented in Table 1) used in the Production Task were presented to the same 17 participants. Each word was heard four times in two trials. In one trial, the word was produced twice in the noun frame sentence, once with first and once with final main stress. In the other trial, both stress possibilities were presented in the verb frame sentence. For each nonword in each sentence frame, the number of responses preferring first syllable stress was divided by the total number of responses, resulting in a proportion of first syllable responses for each word in each sentence frame. The proportions were arcsine transformed and then submitted to a two-way ANOVA.

As in the ANOVA on the production data, the factors of Syllabic Structure (Type 1 CVVCVCC, Type 2 CVCVCC, Type 3 CVCVC or Type 4 CVCVVC) and Lexical Class (noun or verb) were investigated.

First, consider the mean proportion of first syllable stress preference for the four syllable types and two lexical classes displayed in Figure 2. Note that, in general, nouns were more often preferred with initial main stress than verbs were. Also note that Type 1, which has a long vowel in the first syllable, conditioned more first syllable stress preference for both nouns and verbs and that Type 4, which has a long vowel in the final syllable, conditioned more final stress.

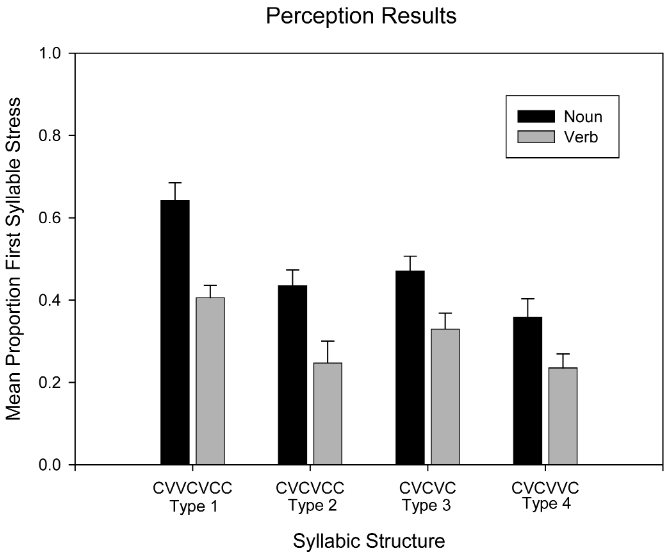

Figure 2

Mean proportions and standard errors of first syllable stress preferences for four nonword types heard by 17 native English speakers, in both noun (black bars) and verb (gray bars) sentence frames

The main effects of Syllabic Structure and Lexical Class were both significant, $F(3, 72) = 12.13, p < .001$ and $F(1, 72) = 35.90, p < .001$ respectively. The interaction was not significant, $F(3, 72) = 1.17$. Nouns were found to have a larger ratio of first syllable stress preference (.51) than verbs (.31). The lack of a significant interaction indicates that the relationship between noun and verb was similar across the four word types and that the effect of Syllabic Structure was consistent across the lexical classes. The main effect of Syllable Structure was explored through Tukey's tests. Type 1 was found to have significantly more first syllable stress preferences than any of the other three types ($p < .01$). In addition, Type 3 had a marginally higher ratio of first syllable stress preference than Type 4 ($p = .08$).

These results indicate that nouns were more likely to be preferred when produced with main stress on the first syllable than verbs were. This preference held for all four syllabic structure types. The syllable structure prediction found to be true for both the nouns and verbs in the Production Task was upheld. Namely, syllables with long vowels were preferred with main stress more often than syllables with short vowels were in words of otherwise comparable syllable structure (i.e., Type 1 had more first syllable stress preferences than Type 2 and Type 3 had marginally more first syllable stress preferences than Type 4). However, stress placement preference for super heavy syllables (CVVC vs. CVCC) did not differ. Nor did the number of coda consonants (CVC vs. CVCC) play a role in stress placement preference.

3.3
Word Similarity Task

The first author listened to the taped responses and coded them as having either first or final syllable stress. The placement of stress was determined by the perceived location of main stress in the word as the participant actually produced it. Only the stress for responses with more than one syllable was recorded. Out of the 680 Trials (40 words × 17 participants), responses were recorded for 358. Most words were disyllabic but a few (around 5% of the cases) were longer. In these cases, the stress was transcribed as first syllable stress for stress on the first syllable and as final syllable stress for stress on the second syllable. No words with primary stress after the first two syllables were produced. Participants responded with more than one word on several trials. In the majority of cases, the second and third word had the same stress as the first word. In a small number of cases (8 or 2.2%), the second word received a different stress from the first. In these cases, the stress of the first word that was said was recorded.

On average, responses for 21 out of 40 trials were recorded per participant. The lowest number recorded was 14 and the highest was 32. There was a wide variety of responses to any given target word, indicating considerable variation in words considered to be phonologically similar among the participants. These results highlight the need for individualized determination of phonologically similar words. Also note that the syllabic structure of the responses did not match the syllabic structure of the nonword in many cases. The Appendix presents the phonologically similar real words produced by the 17 subjects. It will be of interest in the following section to determine whether the stress placement on the similar words can predict stress placement on a novel word even in cases for which the factors of syllable structure and lexical class make different predictions.

3.4
Logistic Regression

The statistical tests presented here were designed to determine what sort of effect three predictor variables had on the assignment of main stress in nonwords. In separate analyses, the ability of three variables to predict the stress placement observed in the Production Task and the Perception Task was assessed. The first predictor variable was the main stress predicted by syllabic structure. The stress placement was predicted in the following manner. If the word has a syllable with a long vowel, it is stressed. If there is no long vowel, a syllable with a coda cluster is stressed. If there is no such syllable, the syllable with a single coda consonant is stressed. This variable will be called "Syllable Structure." The next independent variable, called "Lexical Class," was based on the statistical distribution of main stress between nouns and verbs. Nouns were predicted to have initial main stress and verbs were predicted to have final main stress. The third predictor variable was made up of the results from the Word Similarity Task and will be called "Phonological Similarity." The stress pattern (first or second syllable main stress) of the similar word to a given stimulus item for a given participant was used to predict the stress of that item both in the noun and the verb context. Thus, this variable will make the same prediction as Lexical Class half the time and make a competing prediction the other half of the time. As noted above, the fact that many of the phonologically similar real words did not have the same syllable structure as the nonwords means that the Phonological Similarity factor will also make predictions competing with the Syllable Structure factor in some cases.

Only those cases for which a response was recorded in the Word Similarity Task are included in the regression analysis presented here (53% of the trials presented received responses). Thus, a total of 716 trials were analyzed in each of the production and perception analyses.

As the dependent and independent variables were binary in the data to be analyzed (i.e., first vs. final stress), assumptions for hypothesis testing in linear regression analysis were necessarily violated. For example, a regular distribution of errors could not be assumed. Therefore, a logistic regression analysis was conducted.[6]

The results of the regression analyses indicate that the stress assignments predicted by the variables of Syllable Structure, Lexical Class and Phonological Similarity were *all* significantly associated with the behavioral results from both the Production and Perception Tasks. The stress patterns predicted by these three variables each uniquely contributed to the prediction of stress placement in the stress production task and to the prediction of preference of stress placement in the perception task.

The results from the logistic regression on the production data will be presented first, followed by the results from the perception data.

Production data. The independent variables of Syllable Structure, Lexical Class and Phonological Similarity were entered into a logistic regression model with the dependent variable of main stress placement from the Production Task. Each of the three variables was then removed in turn, allowing for an estimation of the strength of that variable's contribution to the model after the contribution of the other two variables had been partialled out. If removing the variable in question significantly reduced the goodness of fit, it would indicate that the variable made a significant, unique contribution to the model. The effect of the removed variable was estimated by the difference in the −2 Log Likelihood (−2LL), a measure of the goodness of fit. A χ^2 statistic determined the significance of the effect of the change in −2LL.

The results of the regression are given in Table 2. All three predictor variables make a significant contribution to the model. The odds ratio, *Exp(B)*, of 4.6 for the

[6] Logistic regression is suited to situations in which the dependent and optionally the independent variables are dichotomous (Hosmer & Lemeshow, 1989). Different from linear regression analysis, logistic regression directly estimates the probability of an event occurring given the prediction of independent variable(s). The estimated odds ratio, *Exp(B)*, indicates how much greater the odds are of a certain event occurring in one condition versus the odds of that event occurring in another condition. For example, if the odds ratio = 2, then the odds of a given event occurring is two times greater under the predicted condition. The significance of the effect is determined by the Wald statistic. It is customary to use −2 times the log of the likelihood (−2LL) as a measure of how well the estimated model fits the data. Otherwise, logistic regression is similar in function to multiple linear regression and predictor variables can be entered into a model and then removed one at a time, allowing for an estimation of the strength of a given predictor once other variables have been controlled.

factor of Lexical Class indicates that the odds of a nonword being produced with initial stress was 4.6 times greater if it was produced in a noun frame than a verb frame. Likewise, the odds ratio of 2.8 for the factor of Syllable Structure indicates that the odds of a nonword being produced with initial stress was 2.8 times greater if it was predicted to have initial than final main stress by the syllable structure metric outlined above. Finally the odds ratio of 1.7 for the factor of Phonological Similarity indicates that the odds of a nonword being produced with initial stress were 1.7 times greater if the phonologically similar word given in the Word Similarity Task had initial stress.

To estimate the relative strength of the contribution of each of the predictor variables, each variable was removed from the model in turn and the difference in −2LL between the two- versus three-variable model was determined. The results indicate that each variable made a significant, unique contribution to the model. The difference in −2LL when the variable was removed from the model was significant for all three factors. Note that Lexical Class had the greatest effect when removed, followed by Syllable Structure, followed by Phonological Similarity.

TABLE 2

Results from the logistic regression with the results from the Production Task as the dependent variable

Predictor Variables	*B* (*S.E.*)	Wald ($df = 1$)	Odds Ratio	Diff. in −2LL if removed
Lexical Class	1.5 (.18)	73.7 ($p < .001$)	4.6	83.4 ($p < .001$)
Syllable Structure	1.0 (.21)	24.6 ($p < .001$)	2.8	25.2 ($p < .001$)
Phonological Similarity	0.5 (.18)	9.3 ($p = .002$)	1.7	9.5 ($p = .002$)
Constant	−1.1 (.21)	38.3 ($p < .001$)	0.3	

Note: *B* is the logistic coefficient or "logit." The Wald statistic determines the significance of the effect. The odds ratio indicates the factor by which the odds of a predicted value occurring are increased under the condition defined by the independent variable. The lower 95% confidence interval for the odds ratio was above one for all effects reported. The final column presents the change in −2 Log Likelihood (an estimation of the goodness of fit for the model) if the variable in that row is removed. The significance of the removal is determined by a χ^2 test with 1 degree of freedom.

Perception data. The results from the logistic regression with the dependent variable of preference of stress placement from the Perception Task are presented in Table 3. The results are somewhat weaker than those for the production data, but show similar effects. The variables of Syllable Structure, Lexical Class, and Phonological Similarity all are significantly and uniquely related to the preference of stress placement. Note that removal of each of the variables significantly reduces the goodness of fit for the model. The results from the logistic regression analysis are interpreted to mean that initial stress is more likely to be preferred on nonwords that (1) are nouns rather than verbs, (2) have first syllable stress predicted by syllable structure, or (3) are considered to be phonologically similar to a word with first syllable stress.

TABLE 3

Results from the logistic regression with the results from the Perception Task as the dependent variable

Predictor Variables	*B* (*S.E.*)	Wald ($df = 1$)	Odds Ratio	Diff. in −2LL if removed
Lexical Class	0.7 (.16)	18.8 ($p < .001$)	2.0	19.2 ($p < .001$)
Syllable Structure	0.6 (.19)	9.9 ($p < .002$)	1.8	9.9 ($p < .002$)
Phonological Similarity	0.5 (.16)	7.7 ($p = .005$)	1.6	7.8 ($p = .005$)
Constant	−.05 (.19)	7.1 ($p < .008$)	0.6	

Note: B is the logistic coefficient or "logit." The Wald statistic determines the significance of the effect. The odds ratio indicates the factor by which the odds of a predicted value occurring are increased under the condition defined by the independent variable. The lower 95% confidence interval for the odds ratio was above 1 for all effects reported. The final column presents the change in −2 Log Likelihood (an estimation of the goodness of fit for the model) if the variable in that row is removed. The significance of the removal is determined by a χ^2 test with 1 degree of freedom.

Taken together, the results from the logistic regression for the production and perception data indicate that main stress on nonwords can be significantly predicted by the structure of the syllables composing the word, the lexical class of the item (noun vs. verb) and the stress placement of phonologically similar words. Importantly, each of these predictors makes a unique contribution to the regression model. They all have an effect on stress placement that cannot be attributed to any of the other factors.

4 Discussion

The results reported here indicate that main stress is assigned to novel words on the basis of similarity to stored lexical items and knowledge about the distributional patterning of stress placement across the lexicon (i.e., lexical class and vowel length). Knowledge of distributional patterns was shown to affect main stress assignment in both production and perception. First, the statistical patterning of stress by lexical class affected stress assignment. Nouns were more likely to be assigned first syllable stress than verbs, echoing the distributional characteristics of these two lexical classes. Second, stress assignment was affected by the syllable structure of the nonwords, most notably vowel length. In both the production and perception data, syllables with long vowels were more likely to be assigned stress than syllables with short vowels in words of otherwise comparable syllable structure. The production data also indicated that syllables made heavy by long vowels (CVVC) were a better attractor of stress than syllables made heavy by coda consonants (CVCC). However, the effect of one versus two coda consonants in final syllables on main stress placement was inconsistent.

The findings on the effect of vowel length may reflect knowledge of a distribution of stress in which syllables with long vowels are more likely to be stressed than syllables with short vowels, regardless of the presence of coda consonants. To investigate this possibility, the distribution of main stress on long and short vowels in English was estimated with a lexical database. The CELEX lexical database, subdatabase of English word forms, was used (Baayen, Piepenbrock, & Gulikers, 1995). This database contains 160,595 entries of English word forms (i.e., inflected forms in regular use). The number of long vowels [iː eɪ ɑː ɔː əʊ ɜː][7], diphthongs [aɪ aʊ ɔɪ], short vowels [ɪ ɛ æ ʌ ʊ], and schwas [ə] were calculated. Then, the number of times those same vowels received main stress was counted. From these counts, the percentage of instances that the different vowel types received main stress was determined. Of the 92,715 long vowels counted, 54, 772 (59%) had main stress and of the 30,438 diphthong tokens, 19,362 (64%) had main stress. On the other hand, of the 157,105 instances of short vowels, 74,074 (47%) had main stress. There were 52,273 tokens of schwa, none of them stressed. Combining the results from the long and diphthongized vowels on one hand and the results from the short vowels and schwa on the other, we find that long and diphthongized vowels were much more likely to be stressed (60%) than the short vowels and schwa (35%). It seems possible that English speakers have learned this distributional tendency and use that knowledge probabilistically in assigning stress to novel words, as in the experimental tasks described here.

This proposal is consistent with the view that humans can detect, learn and apply statistical regularities. Here, we suggest that English speakers have learned the statistical distribution of stress across lexical classes and vowel length. There is good evidence that animals and humans are sensitive to probabilities in many domains, including language (see the review by Kelly & Martin, 1994). It has been long established that humans are sensitive to, and can reliably estimate, the frequency of words (Shapiro, 1969) and syllables (Rubin, 1974). Recently, Vitevitch, Luce, Charles-Luce, and Kemmerer (1997) have shown that English speakers are also sensitive to the probability of phonotactic configurations. Indeed, Saffran and colleagues have reported that infants use statistical probabilities to learn words (Aslin, Saffran, & Newport, 1998; Saffran, 2001; Saffran, Aslin, & Newport, 1996).

Previous studies have also found evidence of statistical learning in prosodic processing. Reporting on the lexical distribution of stress in English, Cutler and Carter (1987) write that over 70% of content words begin with a strong syllable. In addition, Kelly and Martin (1994) note that, in a corpus of infant directed speech, word boundaries corresponded with strong syllables 95% of the time. English speakers seem to have knowledge of this probability and exploit it for word segmentation. For example, Cutler and Butterfield (1992) reported that when listeners make segmentation errors, they do so by mistakenly putting a word boundary before a strong syllable.

Interestingly, distributional patterns are not the only factors affecting stress placement. The location of stress on a phonologically similar real word also influenced the placement of stress. Importantly, the stress pattern of the phonologically similar word predicted stress independently of the predictions made by syllable structure and the distribution of stress across lexical class. This was found to be the case in regression analyses on both the production and perception data. Thus, it seems that individual lexical items can influence stress placement. This indicates that a similarity metric may operate along dimensions of phonological similarity that are independent of lexical class and syllable

[7] The CELEX database is based on British English. The American equivalents of [əʊ] and [ɜː] would be [oʊ] and [ɝː] respectively.

structure. These dimensions of phonological similarity may be at the level of the individual exemplar or of the segmental pattern shared by the real and nonwords.

This study was only concerned with the placement of main stress on bisyllabic nouns and verbs. The patterns of stress placement for the entire English lexicon are, of course, more complex. Further study with different syllable types, longer words, and more lexical classes will be needed to determine if the factors studied here are predictive of stress placement in English generally. The effect of coda consonants on stress placement should be further investigated by comparing CV to CVC syllables. Also, future research with polysyllabic words could pursue the issue of stress placement in terms of a specific typology of metrical feet.

5 Conclusion

To conclude, let us briefly consider implications these findings have for current models of phonological knowledge. Most importantly, many factors play a role in stress assignment. Syllable structure, lexical class and phonological similarity were investigated here and each was found to play a unique and significant role. It is possible that other factors not investigated here play a role as well. Thus, phonological models would do well to accommodate multiple and competing sources of information leading to predictions about stress placement. These sources may stem not only from metrical structure, but also from lexical class and specific segmental similarities. The latter may function as an analogical, or exemplar-based effect.

One model compatible with such an approach would be that of usage-based phonology (e.g., Bybee, 2001), which proposes that phonological categories and patterns emerge from storage of actual productions and perceptions of individual lexical items. In this theory, generalizations are described as schemas or nonprocess statements about stored items. Schemas are seen as organizational patterns that emerge from statistical regularities in the lexicon. Importantly, on this view, any statistical regularity can be learned and can then be available for application in a novel context. This could include distribution of stress across vowel types and lexical classes as well as the patterning of stress across segmentally similar forms.

Another possibility is to incorporate factors affecting stress placement as constraints in an Optimality Theory (OT) model (Prince & Smolensky, 1993). Such an approach may be able to capture the effects of the multiple factors found to affect stress placement discussed here. An example of this approach with regard to syllable structure can be found in Hammond (1999) where various effects on syllable structure are broken down into individual constraints and ranked.

In standard OT, however, the strict hierarchical ranking of constraints could not account for the probabilistic nature of the effects reported in the current study (see, e.g., McCarthy, 2002). However, there are variants of OT that use a continuous ranking scale (as opposed to a strict domination scale) in which every constraint is assigned a ranking of real number with a regular distribution of variance (see, e.g., Boersma, 1998). Such an approach could potentially account for variability and gradiency of the type reported here. For example, if the distributions of two closely ranked constraints overlap, one constraint will win out over the other in a probabilistic (as opposed to categorical) fashion.

In addition to constraints reflecting probabilistic, distributional patterns, a constraint reflecting the tendency for words with similar segments to have similar stress would also ultimately be needed in an OT approach. Such an approach has been proposed by Burzio (2002) in which the output is analogically relatable to other outputs. Constraints of this type could potentially capture the analogical effects reported here.

In summary, several factors were found to uniquely affect main stress placement on bisyllabic nonwords: lexical class (nouns attracted first syllable stress and verbs final), syllable structure (long vowels were especially found to attract stress) and the extension of the stress pattern of a phonologically similar word. Models of stress placement allowing multiple and potentially competing factors to play a role in stress assignment would be supported by the empirical results presented here.

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Appendix

Words produced in the Word Similarity Task. Only the first word said is listed. Numbers in parentheses indicate the number of times the word was produced. Words beginning in a capital letter are proper nouns.

Stimuli	*Responses with initial stress*	*Responses with final stress*
beɪ bɛkt	baby(5), Babbet, baited, Baywatch	reject
beɪ tɪst	biggest, racist, Baptist (4), better, bassist (2), protest, Babar, baitist	
giː gɛpt	giddy-up, galloped	commence, bereft, inept
giː kɪps	hiccoughs (3)	eclipse, guitar
poʊ bɛkt	podunk, butter, perfect	protect (5), Québec
poʊ tɪst	protest (9), potent (2), boatist, podunk	police, protester
taɪ gɛpt	tiger(2), Tae-Bo, target, tie-dye	
taɪ mɪnz	timing, tie-dye, Timex	amends
tuː kɪps	tulips(7), forceps, toothpicks	
tuː mɪnz	tummy, tumor, tuppence	amends
bɪ bɛkt	beckoned, billow, prefect	bedecked, reject, Québec, dissect, respect, inept
bɪ tɪst	Baptist (3), protest (2), biggest, bitterest, bitter	detest (2), desist, before, protest
dɛ kɪps	rosehips	eclipse, detest
dɛ mɪnz	demons (3), diamonds (2), demon, Damien, linen, demonstrate	demands (3), dements, diminish
kɪ gɛpt	Kitkat	corrupt, verklempt, inept, Québec
kɪ mɪnz	kittens (2), sailing, mittens, linens, Simmons, Kimmins, Cayman, Clemens	commence (2), amends
nɪ gɛpt		neglect (3), negate (2), inept (2), elect
nɪ kɪps	knickers, napkin, Kitkat, naked, hiccoughs	eclipse (2)
sɛ bɛkt	sailor, saber, Sabbath	select (2), inspect, sabbatical, Sebastian
sɛ tɪst	sadist (5), saddest (2), sentiment, protest, Satan, sedative, scientist, separatist	
bɪ lɪn	building (2), linen, bailing, Berlin	Berlin (9), Belin (name), believe, Milan
bɪ tɛs	bitter (3), dentist, bitten, bitterness, Baptist	detest (3), bidet

dɛ lɛt	letter, dollop	delete (4), delight (2), deflect
dɛ sɪn	listen, Datsun	de-line, descend (6), design (3), desist, Disan (name)
kɪ gɛt		forget (3)
kɪ tɛs	kittens (3), cutest, kiosk, kitten, kitties, contest	
nɪ lɛt	scarlet, nibblet, letter, inlet, toilet	Gillette (3), neglect, Ninet (name)
dɛ sɪn	Nissan (2), Nixon, lesson, Nisa, listen, Nissin, nation	resend, ascend, descend
sɛ gɛt	Saget (3), secret (2), cigarette, segregate, nougat	select (2), forget (2), següe
sɛ lɪn	selling (4), sailing (2), salad (2), linen, silent, Sarah	saline (2), Berlin
bɪ teɪs	bitter	bidets, erase
bɪ toʊs	bitter (4), comatose	
dɛ guːt	dagger, detriment	Ragu
dɛ toʊs	dextrose (2), glucose	detest (3), de-tox (3), Detroit
kɪ giːn	kicking (4), making, rigging, guillotine, keeping	gangrene, again
kɪ teɪs	kitten (4), kitties	catastrophe, cryptase
nɪ guːt	nougat (2), neither, nugget	negate (3), Beirut, neglect (2)
nɪ liːt	litter	elite (11), Nilini (name)
sɛ giːn	sanguine (2), sagging, sucking	again
sɛ liːt	solid	elite (6), select (2), salute (2), secrete