AN INSTRUMENTAL STUDY OF VOWEL REDUCTION AND STRESS PLACEMENT IN SPANISH-ACCENTED ENGLISH

James Emil Flege
Ocke-Schwen Bohn
University of Alabama, Birmingham

Morphophonological alternations in English words such as able versus ability involve changes in both stress and vowel quality. This study examined how native speakers of Spanish and English produced four such morphologically related English word pairs. Degree of stress and vowel quality was assessed auditorily and instrumentally. Stress placement generally seemed to constitute less of a learning problem for the native Spanish speakers than vowel reduction. The results suggest that English-like stress placement is acquired earlier than vowel reduction and that the ability to unstress vowels is a necessary, but not sufficient, condition for vowel reduction. The magnitude of stress and vowel quality differences for the four word pairs suggests that L2 learners acquire stress placement and vowel reduction in English on a word-by-word basis.

INTRODUCTION

Many second language (L2) learners retain a foreign accent long after achieving proficiency in other aspects of L2 production. A foreign accent may result from segmental substitutions of replica for model sounds as well as non-L2-like rhythmic, intonational, and stress patterns (Flege, 1984). Even though it is generally agreed that

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the use of full instead of reduced vowels in unstressed syllables may contribute importantly to foreign accent and this phenomenon “is extremely typical” (Hammond, 1986) in Spanish-accented English, to our knowledge it has never been examined empirically.

This study examined vowel reduction and stress placement in morphologically related English words spoken by native speakers of Spanish and of English. The phenomena of interest are illustrated by the word pair *botany–botanical*. The first word has main stress on the first vowel (unreduced /ɑ:/ in American English), whereas the second word has an unstressed first syllable with the reduced vowel schwa (/ə/).

English has an elaborate derivational morphology which frequently involves such morphophonological alternations. Although English first language (L1) and L2 acquisition have been studied in more detail than that of any other language, little is known about how learners acquire English derivational morphology and how they process morphophonological alternations. The acquisition of English morphophonology in the inflectional paradigms, which does not involve the learning of stress alternations, is fairly well understood with respect to both L1 acquisition (Berko, 1958; Brown, 1973; Derwing & Baker, 1986; MacWhinney, 1978) and L2 acquisition (Natalicio & Natalicio, 1971; Wode, 1981). Some of these studies also comment briefly on the acquisition of morphophonological alternations in derivational morphology, suggesting that inflectional morphology is learned before derivational morphology, which is initially restricted to affixation without concomitant phonological changes (e.g., *teach–teacher*). Examining how learners treat morphologically related words with segmental and suprasegmental differences may be hindered by the fact that this aspect of English morphophonology is learned late and takes long to master completely. Carlisle (1987) found that even native English-speaking 13-year-olds are not fully competent speakers of their L1 with respect to their mastering of pairs like *decide–decision*.

The apparent difficulty of learning morphophonological alternations in derivational morphology is matched by the complexity of their linguistic descriptions. Inflectional suffixes such as preterite *-ed* and plural *-s* are fully predictable with respect to their allomorphs but derivational affixes are not, as can be seen by considering the adjectives derived from *botany, irony, Satan, and economy*, namely, *botanical, ironic/ironical, satanic, and economic or economical*. To use the suffixes *-ic* and *-ical* appropriately, the learner has to acquire word-specific knowledge. Such knowledge is not as necessary for inflectional morphology. Furthermore, morphophonological alternations frequently exhibit consonant changes (e.g., *electric–electricity*), vowel changes (e.g., *decide–decision*), and stress placement changes (e.g., *Satan–satanic*). Some morphophonological alternations can be described by rules, but others are idiosyncratic and must be learned on a word-by-word basis (compare *serene–serenity* to *obese–obesity*).

This study examined two aspects of the learning tasks just mentioned: vowel alternations involving vowel reduction and stress placement. To illustrate the problems that native speakers of Spanish face in dealing with these phenomena in English, we will comment on Spanish–English differences that are related to these phenomena.
Rhythmic Patterns

Spanish and English have different rhythmic patterns. Languages with differences in rhythmic patterns have traditionally been classified as being either stress-timed or syllable-timed. Although this dichotomy appears to be problematic (especially with regard to the notion of stress-timing, see Adams, 1979; Roach, 1982), English may be considered stress-timed in the sense that intervals between stressed syllables tend to be of equal length, whereas Spanish is syllable-timed in its tendency to have syllables of equal length. One might therefore expect the duration of English syllables to vary according to the number of syllables in a rhythmic unit, but not for Spanish syllable duration to be influenced by the number of unstressed syllables between two fully stressed syllables. In support of this, Delattre (1966) found the average ratio of stressed to unstressed syllable durations to be greater in English than in Spanish. Because of the different rhythmic patterns, vowel reduction in relatively unstressed syllables may be a means to achieve isochronism in English but not Spanish (see also Roach, 1982).

Freedom of Stress Placement

English and Spanish have relatively free stress as opposed to languages with fixed stress on one position in words or phrases such as Czech or Polish. Fixed-stressed languages should pose less of a learning problem since stress is fully predictable and uniformly applied. In languages with relatively free stress, stress may have phonemic value and therefore has to be learned as a property of lexical items.

Free-stressed languages have some segmentally identical words that differ only according to which syllable is stressed, as in Spanish término–termino–terminó (‘term’–‘I terminate’–‘he/she terminated’). Corresponding English examples are hard to find. As noted by Stockwell and Bowen (1965), word pairs like convict–convict also differ in vowel quality. However, at least for some native speakers of English, word pairs like réefer–refér, differ–defer, and pévert–pervért are differentiated solely by stress.

Stress Placement

To understand stress placement regularities in English and Spanish, it is first necessary to comment briefly on the number of stress levels in the two languages. Most descriptions of Spanish recognize two stress levels, strong and weak (Navarro, 1967). There is less agreement on how many stress levels there are in English. The number of levels recognized in the literature ranges from two (Ladefoged, 1975) to five (Chomsky & Halle, 1968). The widely accepted impressionistic linguistic levels of primary stress, secondary stress, and no stress were used initially for auditory judgments in the present study, but since multilevel stress systems “are not in accord with the phonetic facts” (Ladefoged, 1975, p. 101) we later focused on the binary contrast of stress (including primary and secondary stress) versus no stress, as advocated by Ladefoged (1975) and Quirk, Greenbaum, Leech, and Svartvik (1972).
Spanish exhibits less complex stress placement regularities than English (see Stockwell & Bowen, 1965). Perhaps most importantly, only one of the last three syllables in a monomorphemic word can carry stress. Different regularities account for stress placement in Spanish verbs and nonverbs. According to Harris (1983), “segmental phonological representation and morphological identification are jointly necessary and sufficient” to determine word stress in all verb forms, whereas in nonverb forms, “segmental representation and morphological characterization are [necessary but] not sufficient” (p. 84) to determine stress. Still, a substantial number of Spanish nonverbs seem to be subject to the Latin stress rule (Foley, 1965), which assigns stress to either the penultimate or the antepenultimate syllable, according to the structure of the penultimate.

English has greater freedom of stress placement than Spanish. Although word stress in English is difficult to predict, it seems that native speakers rarely disagree on stress placement in unfamiliar words. There have been numerous attempts to state these regularities (e.g., Chomsky & Halle, 1968), but no treatment to date accounts for English stress placement without much residual data and ad hoc descriptions. Research indicates that stress placement can be predicted for many English words based on knowledge of some or all of the following properties: word class, morphological structure, number of syllables, and syllable structure. However, certain subregularities may simplify the learner’s task. For instance, stress is fully predictable in words with certain affixes, for example, stress always falls on the syllable immediately preceding the derivational suffixes -ion (as in application), -ic(al) (as in satanic, botanical), and -ity (as in ability).

Phonetic Correlates of Stress

Speech research has resulted in some agreement on which phonetic dimensions are involved in the production and perception of stress, and also on the ranking of these parameters as cues to stress. The three most important dynamic phonetic correlates of stress in articulatory terms are change of tension in vocal folds, change in timing of articulatory movements, and change in subglottal pressure. The respective acoustic manifestations are change of fundamental frequency (F₀), change in length, and change in amplitude/intensity. The corresponding auditory correlates are change in pitch, change in duration, and change in loudness. These correlates are not independent of other factors, or of each other. For instance, vowel quality and phonetic environment influence the phonetic realization of stress along all three dimensions, and fundamental frequency and amplitude may interact in complex ways (see Couper-Kuhlen, 1986).

It is generally agreed that the production and perception of stressed syllables cannot be attributed to any one parameter (see Crystal, 1969). However, this does not mean that the various acoustic correlates of stress are equally important cues in stress perception. It appears that these cues are hierarchically ordered in English: An F₀ change is the most important cue, increased duration less important, and increased intensity least important (see Adams, 1979; Lehiste, 1970). Berinstein (1979) suggested that
this constitutes a universal unmarked hierarchy in languages with no phonetic contrasts in tone or vowel length. She found no evidence that Spanish differs from English with respect to the proposed hierarchy (see also Bolinger & Hodapp, 1961), but Delattre's (1966) cross-linguistic data suggest that duration may be a less important cue to stress in Spanish than English.

**Stress and Vowel Alternations in Morphologically Related Words**

Both English and Spanish have some suffixes which “move” stress to a different syllable in a derived word, whereas other suffixes do not affect stress placement. (Compare Spanish poblán—población to esperán—esperanza, and English botán—botánical to delight—delightful.) Stress placement in words with derivational suffixes is much more predictable than stress placement in monomorphemic words since each suffix determines (primary) stress placement in a straightforward manner in both languages.

In Spanish and English, derivation may not only bring about changes in stress placement but also phonological changes. This can be seen in Spanish nuevo—novedad and in English botán—botánical. One major difference between the two languages is that only English has alternations involving vowel reduction in unstressed syllables (compare the first vowel in botán to the first vowel in botánical). Although the reduced vowel in English is usually transcribed as schwa (\(\text{\textael}\)), it may also be realized as a high or low central vowel, transcribed as [i] and [\(\text{\textael}\)], respectively (Kantner & West, 1960). Unlike English, Spanish does not have reduced vowels. Stress is said to have no effect on the quality of vowels in Spanish.

Linguistic treatments of phonological alternations in morphologically related words differ considerably. Chomsky and Halle (1968) and Hudson (1980) present quite different approaches (see Dressler, 1985). Chomsky and Halle conflate morphophonology and phonology in their attempt to describe morphophonological alternations with phonological rules, whereas Hudson views these alternations as suppletions. The psycholinguistic implications of these two approaches are that speakers attempt to minimize either storage or computation (Lass, 1984, p. 205). Whether or not, or to what extent, learners become competent speakers through rule-governed acquisition (computation) or rote learning (storage) is uncertain for both L1 and L2 acquisition, but there is evidence that which strategy is favored depends on the stage of acquisition and on which property of the target language is being acquired (see Bohn, 1986).

Little is known about mature speakers’ mental representations of morphophonological alternations in derivational morphology, but neither position just outlined seems to be entirely correct (see Dressler, 1985). MacWhinney (1975, 1978) studied the contribution of what was called rote, analogy, and combination to the L1 acquisition of morphophonology in the inflectional paradigms of a number of languages, but it appears doubtful whether his results can be extended to the acquisition of derivational morphology by either L1 or L2 learners. Different modes of learning and storage for inflected as opposed to derived forms are suggested by Sterling’s (1983) investigation of native English speakers’ spelling errors. These errors indicate that inflected forms are produced...
by rule application, whereas derivational forms are memorized. Marshall’s (1987) study of morphological effects in native English speaker’s auditory lexical access points in a similar direction. He found that regular inflected forms and derived forms with highly productive affixes that do not affect the phonological makeup of the stem are accessed in conjunction with their stem, whereas other derived forms have separate entries. To our knowledge, no study has addressed this issue with respect to L2 acquisition.

The Learning Problem

The learning problem of native Spanish speakers of L2 English may be summarized as follows: Spanish speakers have to acquire a different (i.e., stress-timed) rhythmic pattern in which relatively unstressed syllables tend to be considerably shorter than their Spanish counterparts. Since both languages have free stress, Spanish learners of English will be familiar with the use of variable stress placement to differentiate segmentally identical lexical items. However, even if the two languages are assumed to differentiate only two stress levels (i.e., stressed versus unstressed), Spanish learners of English face an extremely complex set of stress placement regularities in their second language.

Spanish speakers of L2 English might react to this problem by learning stress patterns on a word-by-word basis, by relying on Spanish stress placement regularities (especially in cognates), or by making use of subregularities of English stress placement. Native speakers of Spanish need not acquire a new hierarchy of phonetic correlates to implement stress in English, since the only apparent difference between the two languages seems to be the greater duration ratio of stressed to unstressed syllables in English.

Although stress and vowel alternations in morphologically related words are familiar to native speakers of Spanish, there are a number of ways in which they could treat English alternations. Learners might rely completely on Spanish stress placement regularities and produce substitutions for alternating vowels. This is likely to be the case in alternations involving vowel reduction, since Spanish does not have reduced vowels. They might show evidence of a separate treatment of stress and vowel alternations where one might be a prerequisite for the other. Or, their productions could indicate that stress and vowel alternations are learned simultaneously. It is also possible that L2 learners will learn stress and/or vowel alternations on a word-by-word basis, mastering alternations in some morphologically related words earlier than in others.

The inability of some L2 speakers of English to reduce vowels in appropriate contexts has been demonstrated instrumentally in connected utterances (Adams & Munro, 1978) and read word lists (Fokes, Bond, & Steinberg, 1984). Fokes et al. suggested that production of a full instead of a reduced vowel in the second syllable of words such as confirmation caused some of their L2 English speakers to use inappropriate phonetic correlates to implement the contrast of stressed versus unstressed vowels in morphologically related words.

The hypothesis that an Englishlike stress implementation depends on L2 learners’
ability to produce reduced vowels will be investigated in this study. However, the primary aim of this study was to shed light on L2 learners’ treatment of stress and vowel alternations in morphologically related English words. In particular, we were interested in determining how native speakers of Spanish place stress in these words and whether they reduce vowels appropriately. This was done by comparing the productions of seven native Spanish speakers to those of seven native English speakers. Stress placement was assessed both auditorily (i.e., through transcriptions) and instrumentally through an analysis of two acoustic correlates of stress (intensity and duration). Vowel quality was examined auditorily through transcriptions and instrumentally through a physiological analysis of tongue position.

METHODS

Subjects

The native English-speaking group consisted of seven women with a mean age of 36 years ($SD = 3$). Four were born in Alabama, and all had lived for many years in Birmingham, Alabama, at the time of the study. None could speak a language other than English. The native Spanish-speaking group consisted of seven women with a mean age of 32 years ($SD = 8$) who had arrived in the United States at a mean age of 29 years ($SD = 7$) and lived there for an average of 2.3 years ($SD = 2$). These women came from several Latin American countries (El Salvador–1, Mexico–1, Colombia–3, Guatemala–1, Ecuador–1), had studied English formally in school for an average of 4.4 ($SD = 1.3$) academic years, and spoke English with a noticeable foreign accent in the authors’ opinion.

Procedures

The women each produced the following four pairs of morphologically related words:

<table>
<thead>
<tr>
<th>stressed:</th>
<th>unstressed:</th>
</tr>
</thead>
<tbody>
<tr>
<td>able</td>
<td>ability</td>
</tr>
<tr>
<td>Satan</td>
<td>satanic</td>
</tr>
<tr>
<td>application</td>
<td>apply</td>
</tr>
<tr>
<td>botany</td>
<td>botanical</td>
</tr>
</tbody>
</table>

The first syllable of words in the first row receives stronger stress than the first syllable of the words in the second row. These pairs were mentioned by Stockwell and Bowen (1965) as being illustrative of the phenomenon of vowel reduction. Of these words, all but able have cognates in Spanish. Of the stressed vowels in the first syllable, English /eɪ/ has an obvious counterpart in Spanish, whereas counterparts for English /ɑ/ and /æ/ are less certain.

The analyses focused on the first (italicized) vowels in the given words. The native speakers of English were expected to produce the first vowels in the second row with
Table 1. Words said by the experimenter in the presence of the Spanish-speaking women prior to data acquisition\textsuperscript{a}

<table>
<thead>
<tr>
<th>Word</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>S6</th>
<th>S7</th>
</tr>
</thead>
<tbody>
<tr>
<td>apply</td>
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<td></td>
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<td></td>
<td></td>
<td>x</td>
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<tr>
<td>application</td>
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<td>x</td>
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<td></td>
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<td></td>
<td>x</td>
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<tr>
<td>Satan</td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
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<tr>
<td>satanic</td>
<td></td>
<td></td>
<td>x</td>
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<td></td>
<td>x</td>
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<tr>
<td>able</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
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<td></td>
<td>xxx</td>
</tr>
<tr>
<td>ability</td>
<td></td>
<td>xxx</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>botany</td>
<td>x</td>
<td></td>
<td>xxx</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>botanical</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
</tbody>
</table>

\textsuperscript{a}The number of xs indicates the number of repetitions.

The women, who were seated comfortably in a dental chair with their head against a headrest, were unaware of the aim of the experiment. They read the words in the first row, then the words in the second row, five times each. Several requested information about the meaning or about the pronunciation of certain words. Table 1 lists those instances in which the experimenter pronounced one of the test words in the woman's presence. As discussed later, this does not seem to have affected pronunciation systematically.

Two microphones were positioned in front of the speaker. The one positioned at about 15 cm from the mouth was connected to a Technics (Model M235X) tape recorder. The audiotape was used later for a transcriptional analysis. The microphone placed at 30 cm from the mouth was connected to a filterbank, the output of which was digitized with 12-bit amplitude resolution. The intensity data transduced by the second microphone was used to make intensity comparisons between nominally stressed and unstressed syllables.

The vertical distance of the tongue from the hard palate in vowels was measured using glossometry. This operation of the glossometer, as well as the placement of the optical sensors needed for making measurements, have been described previously (see Flege, Fletcher, McCutcheon, & Smith, 1986, and references therein). The women spoke while wearing an approximately 0.3 mm thick plastic pseudopalate, which conformed closely to the maxillary teeth and hard palate. It has been shown that wearing a pseudopalate does not interfere perceptibly with vowel production (Flege, 1986).

Four small optical sensor assemblies were embedded in the pseudopalates along the palatal midline. The first sensor was positioned just posterior to the alveolar ridge. The remaining sensors were positioned at approximately 11-mm intervals so that sensor 4 was several millimeters anterior to the juncture of the hard and soft palates. The light emitting diodes (LEDs) in each assembly emitted a beam of light downward toward the dorsal surface of the tongue. The quantity of light transduced by the associated phototransistor was (after linearization) roughly in-
versely proportional to the square of the distance of the tongue from the hard palate. The tongue–palate distances were digitally sampled at 100 Hz and stored on disk along with the intensity values.

**Transcriptions**

One of the researchers transcribed the first vowels in each word. Judgments were made concerning the degree of stress and vowel quality. Each vowel was transcribed as having primary word stress, secondary stress, or as being unstressed. Based on the transcriptions, a decision was made concerning whether the first vowel in each word pair received the same or different degree of stress. If both vowels were transcribed as unstressed, they were marked u. If the vowels received differing degrees of stress, the vowel with the greater degree of stress was marked s. For example, an s and a u for able and ability means that the first vowel in able received greater stress than the first vowel in ability.

**Instrumental Analyses**

The intensity and tongue–palate distances were displayed on a graphics terminal, as shown in Figure 1. Intensity is displayed in the top panel, and tongue–palate distances at the three most anterior sensors in the remaining three panels. The vowel interval was measured acoustically from the increase above baseline of root mean square (RMS) intensity associated with release of the prevocalic consonant, to the rapid decrease in intensity which signaled consonantal constriction. Vowel duration was computed by multiplying the number of frames within the segmented interval by 10 ms. The frame within the segmented interval with greatest intensity was chosen and converted to a decibel (dB) value. The mean duration and peak intensity values in the multiple productions of each word were calculated for each speaker. Data for one Spanish speaker (S6) were missing due to an equipment malfunction.

A single frame, indicated by the dotted line in Figure 1 was chosen to represent the tongue position in each vowel. This frame typically represented the end of a tongue-raising or lowering gesture. As seen in Figure 1, the tongue–palate distances at sensors 2 and 3 increased up to the segmentation point (indicating downward tongue movement) then began decreasing.

The native English speakers showed two clear movement trajectories for the diphthongal vowel in able, so two sets of tongue–palate distances were obtained for these vowels. The first was designated the onglide and the second the offglide of [e1]. The mean tongue–palate distances at the four sensors in the multiple productions of each word were calculated. Values could not be obtained for the following words owing to saliva artifacts (see Flege et al., 1986): apply (S5, E5), application (S5), botany (S6, E4).
Figure 1. Illustration of how the target vowels were segmented. Intensity (in volts) is shown in the top panel, and vertical tongue–palate distances (in mm) at the three most anterior sensors are shown in the bottom three panels. B and E define the beginning and the end of the vowel; T indicates the target frame chosen for the tongue-distance analysis.
Table 2. Transcription of stress in four word pairs produced by native speakers of English (E1–E7) and Spanish (S1–S7): “s” indicates a greater degree of stress than “u”.

<table>
<thead>
<tr>
<th>S</th>
<th>able—ability</th>
<th>Satan—satanic</th>
<th>application—apply</th>
<th>botany—botanical</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>s u</td>
<td>s u</td>
<td>s u</td>
<td>s u</td>
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<tr>
<td>E2</td>
<td>s u</td>
<td>s u</td>
<td>s u</td>
<td>s u</td>
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<tr>
<td>E3</td>
<td>s u</td>
<td>s u</td>
<td>s u</td>
<td>s u</td>
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<tr>
<td>E4</td>
<td>s u</td>
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<td>E5</td>
<td>s u</td>
<td>s u</td>
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<tr>
<td>E6</td>
<td>s u</td>
<td>s u</td>
<td>s u</td>
<td>s u</td>
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<tr>
<td>E7</td>
<td>s u</td>
<td>s u</td>
<td>s u</td>
<td>s u</td>
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<tr>
<td>S1</td>
<td>s u</td>
<td>s u</td>
<td>u u</td>
<td>s u</td>
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<tr>
<td>S2</td>
<td>s u</td>
<td>s u</td>
<td>u u</td>
<td>s u</td>
</tr>
<tr>
<td>S3</td>
<td>s u</td>
<td>s u</td>
<td>u u</td>
<td>s-2/u-3 s-1/u-4</td>
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<tr>
<td>S4</td>
<td>s u</td>
<td>u u</td>
<td>u u</td>
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<td>S5</td>
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<td>S6</td>
<td>s u</td>
<td>u u</td>
<td>u u</td>
<td>s u</td>
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<tr>
<td>S7</td>
<td>s u</td>
<td>s u</td>
<td>u u</td>
<td>s u</td>
</tr>
</tbody>
</table>

RESULTS

Stress Placement

Transcriptions. The transcribed values for stress are presented in Table 2. The native English and Spanish speakers all produced the first vowel in able with greater stress than the first vowel in ability. The same was true for Satan—satanic with but two exceptions. For Spanish speakers S4 and S6, both vowels were unstressed. The English speakers all produced the first vowel in botany with greater stress than the first vowel in botanical. However, the vowels in both words as produced by Spanish speaker S5 were unstressed; and one other Spanish speaker (S3) was variable. The greatest difference between the two groups was for the application—apply pair. Whereas both vowels were heard as unstressed in the Spanish speakers’ productions, the English speakers uniformly produced the first vowel in application with greater stress than that in apply.

Vowel duration. The transcriptions for stress suggested there might be little difference between the Spanish and English speakers for the able—ability pair, a small difference for Satan—satanic and botany—botanical (owing to the productions of just two speakers), and a more substantial between-group difference for application—apply. This was tested by examining the relative duration of the first vowels in each pair. The 8 words × 15 speakers = 120 mean vowel durations were submitted to a three-way ANOVA in which stress (nominal stress versus unstressed) served as a repeated measure.

The results of this analysis were consistent with the transcriptions. Figure 2 shows
Figure 2. Mean duration (in ms) of stressed and corresponding unstressed vowels in words spoken by native speakers of English (top) and Spanish (bottom); the brackets enclose ± one standard deviation.
the mean duration of the first vowels in each word pair spoken by native speakers of Spanish and English. The English speakers produced the first vowels in *able*, *Satan*, *application*, and *botany* with longer mean durations than those in *ability*, *satanic*, *apply*, and *botanical*, respectively. The duration differences averaged 106 ms. The Spanish speakers produced a difference in all pairs except *apply-application*. The average duration differences in the three remaining pairs averaged 86 ms for the Spanish speakers.

The ANOVA yielded a Group × Word Pair × Stress interaction, $F(3,43) = 2.87, p < .05$, because the duration difference for all pairs was significant except for the Spanish speakers’ productions of *apply-application* ($p < .05$). The English speakers produced stressed vowels with greater duration than unstressed vowels in every instance. For the Spanish speakers, a duration difference was always observed in *able-ability*, *Satan-satanic*, and *botany-botanical*. In *application-apply*, however, the expected difference was not seen for three speakers, and the duration differences for the remaining speakers were quite small. This is not surprising since no difference in degree of stress was perceived in *application-apply* for any Spanish speaker.

To assess the magnitude of the stress-related duration differences, the ratio of vowel durations was computed for each word pair. One-way ANOVAs revealed that the ratios were significantly greater for English than Spanish speakers in *Satan-satanic* (3.5 versus 2.0), *application-apply* (1.9 versus 1.0), and *botany-botanical* (3.0 versus 1.6) ($p < .05$). The ratios computed for the English and Spanish speakers in *able-ability* (3.1 versus 2.8) did not differ significantly.

**Vowel intensity.** Results of the intensity analysis were also consistent with the transcriptions of stress. Both the Spanish and English speakers used intensity as a correlate of stress. Figure 3 shows the mean intensity of vowels in the four word pairs. Both the native English and Spanish speakers produced the first vowels in *able*, *Satan*, *application*, and *botany* with greater intensity than those in *ability*, *satanic*, *apply*, and *botanical*.

The Group × Stress interaction reached significance because the English speakers produced a greater peak intensity difference between vowels in the word pairs (75.5 versus 71.8 dB) than the Spanish speakers (70.3 versus 68.2 dB), $F(1,43) = 5.06, p < .05$. The Group × Stress × Word Pair interaction was nonsignificant.

The native English speakers produced stressed vowels with greater intensity than unstressed vowels in every instance. For the Spanish speakers, the expected intensity difference was observed in all but one instance where a stressed-unstressed difference was transcribed. An intensity difference in the same direction was observed in 10 instances where no stressed-unstressed difference was transcribed. This may reflect the existence of subperceptual differences in stress implementation.

The ratio of peak intensity seen in the first vowels of each pair was computed. To evaluate the magnitude of the stress difference, the intensity ratios were submitted to one-way ANOVAs. The English and Spanish speakers did not differ sig-
Figure 3. Mean RMS intensity (in dB) of stressed and corresponding unstressed vowels in words spoken by native speakers of English (top) and Spanish (bottom); the brackets enclose ± one standard deviation.

Significantly for able—ability (1.04 versus 1.06), Satan—satanic (1.05 versus 1.01), or application—apply (1.03 versus 1.01). But the English speakers showed significantly larger ratios than the Spanish speakers for botany—botanical (1.07 versus 1.03) ($p < .05$).
Table 3. Transcription of vowel quality in four word pairs produced by native speakers of English (E1–E7) and Spanish (S1–S7)\(^a\)

<table>
<thead>
<tr>
<th>S</th>
<th>able–ability</th>
<th>Satan–satanic</th>
<th>application–apply</th>
<th>botany–botanical</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>ei (\Lambda)</td>
<td>el (i)</td>
<td>ae (\Lambda)</td>
<td>a (\varnothing)</td>
</tr>
<tr>
<td>E2</td>
<td>ei (\Lambda)</td>
<td>el (i)</td>
<td>ae (\Lambda)</td>
<td>a (\varnothing)</td>
</tr>
<tr>
<td>E3</td>
<td>ei (\Lambda)</td>
<td>ei (i)</td>
<td>ae (\Lambda)</td>
<td>a (\varnothing)</td>
</tr>
<tr>
<td>E4</td>
<td>ei (\Lambda)</td>
<td>el (i)</td>
<td>ae (\Lambda)</td>
<td>a (\varnothing)</td>
</tr>
<tr>
<td>E5</td>
<td>ei (\Lambda)</td>
<td>el (i)</td>
<td>ae (\Lambda)</td>
<td>a (\varnothing)</td>
</tr>
<tr>
<td>E6</td>
<td>ei (\Lambda)</td>
<td>el (i)</td>
<td>ae (\Lambda)</td>
<td>a (\varnothing)</td>
</tr>
<tr>
<td>E7</td>
<td>ei (\Lambda)</td>
<td>el (i)</td>
<td>ae (\Lambda)</td>
<td>a (\varnothing)</td>
</tr>
<tr>
<td>S1</td>
<td>e(i)</td>
<td>e(a)</td>
<td>a</td>
<td>a</td>
</tr>
<tr>
<td>S2</td>
<td>e(a)</td>
<td>e(a)</td>
<td>a</td>
<td>a</td>
</tr>
<tr>
<td>S3</td>
<td>e(i)</td>
<td>el (a)</td>
<td>a</td>
<td>a</td>
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<tr>
<td>S4</td>
<td>e(i)</td>
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<td>S5</td>
<td>e(i)</td>
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</tr>
<tr>
<td>S6</td>
<td>e(i)</td>
<td>e(a)</td>
<td>a</td>
<td>a</td>
</tr>
<tr>
<td>S7</td>
<td>e(i)</td>
<td>el (i)</td>
<td>a</td>
<td>a</td>
</tr>
</tbody>
</table>

\(\varnothing\) is used for \([i]\); \([e\(i\)]\) indicates less diphthongisation than \([ei]\); \([i]\) is a high central unrounded vowel.

Vowel Quality

Transcriptions. Table 3 summarizes the transcriptions of the first vowels in the eight words spoken by each speaker. A vowel quality difference between the stressed and unstressed vowels produced by the English speakers was heard in every instance. The unstressed first vowel in *botanical* was heard as schwa for all speakers except E2, who produced it as \([o]\). This may have been a spelling pronunciation. The unstressed first vowels in *ability* and *apply* were heard as reduced to \([\Lambda]\) rather than schwa (see the section earlier on stress and vowel alternations). The unstressed vowels in *satanic* were heard as \([i]\), probably due to carry-over coarticulation from the preceding \([s]\).

The native Spanish speakers were heard to produce vowel quality differences in 16 of 28 instances, albeit not the same ones produced by the English speakers. In the remaining 12 instances, the Spanish speakers were not heard to have produced a vowel quality difference: *Satan–satanic* (S4, S5, S6), *application–apply* (S1–S5), *botany–botanical* (S2, S4–S6).

Tongue configurations. Figure 4 shows the mean position of the tongue in the first vowels of *able* and *ability* as spoken by four of the subjects. Each panel in Figure 4 shows a midsagittal contour of one speaker's hard palate. The tongue positions were plotted by fitting a third-order polynomial regression line to the mean tongue–palate distance values observed at the four glossometer sensors.

Examination of the tongue position data showed that, as expected from the transcriptions, both the English and Spanish speakers produced large differences between the first vowels in *able–ability*. This is illustrated for one English speaker and three Spanish speakers in Figure 4. As illustrated by speaker E7, the native English speakers strongly diphthongized the vowel in *able*. Note that the tongue was much higher in the
Figure 4. The mean position of the tongue with reference to four sensors (1–4) located along the hard palate. The panel for English speaker E7 (upper left) shows the tongue position for the onglide and offglide of the stressed (+STR) vowel [eɪ] in able and the corresponding unstressed (−STR) vowel in ability. The remaining panels show values for monophthongal stressed and unstressed vowels in able and ability as spoken by three representative Spanish speakers (S1, S2, S5). The + symbol in this and following figures marks the tip of the central maxillary incisors.
offglide than onglide of [eɪ], and much higher in the onglide of [eɪ] than in the monophthongal vowel [ʌ] in *ability*. The Spanish speakers did not diphthongize the vowel in *able* to the extent that two clearly defined tongue positions were evident visually. Like the English speakers, the Spanish speakers produced the vowel in *able* with a much higher tongue position than the vowel in *ability*.

Figure 5 reveals that the Spanish speakers produced considerably smaller tongue position differences between the vowels in *botanical–botany* than the English speakers. The data for English speaker E3 illustrate that, as expected from the transcriptions, the English speakers produced the first vowel in *botany* with a lower tongue position than the first vowel in *botanical*. Spanish speaker S4 showed a small difference, albeit one in the direction opposite to that observed for the English speakers. However, as noted earlier, this did not result in an audible difference in vowel quality. As expected from the transcriptions, S2 and S5 produced *botany–botanical* with the same tongue positions.

The data for English speaker E1 in Figure 6 are representative of the English speakers' productions of *Satan–satanic*. Their *satanic* had a relatively high tongue position owing to the preceding [s]. The vowel they produced in *Satan* had a slightly lower tongue position and was not strongly diphthongized. The Spanish speakers produced even smaller tongue differences. As expected from the transcriptions, S2 and S3 showed tongue position differences and S6 did not.

The data for speaker E3 in Figure 7 illustrate the English speakers' productions of *application–apply*. The tongue was only slightly lower for *application* than *apply*. Despite this, a clear vowel quality difference was heard. It is likely that an important aspect of the physiological distinction between American English [ʌ] and [æ] is a difference in pharyngeal cavity width, which cannot be observed using the glossometer. The Spanish speakers also showed small tongue position differences but, unlike the English speakers, no difference in vowel quality was heard between the first vowels they produced in *application* and *apply*.

**Average tongue height.** To quantify the magnitude of the tongue differences, the average vertical height of the tongue from the hard palate at the four sensor locations was computed for each vowel token. A mean value was then computed of the averages obtained in the multiple tokens of each word and submitted to a mixed-design ANOVA. Figure 8 shows the mean tongue–palate distances observed for the eight words. (Note that as the tongue lowers in the mouth, tongue–palate distances increase). As expected, the English speakers produced all pairs except *application–apply* with substantial vertical tongue height differences. The native Spanish speakers, on the other hand, did so for only the *able–ability* pair, which led to a significant Group × Word Pair × Stress interaction, $F(3, 44) = 12.1, p < .01$.

The interaction was explored by testing the effect of Stress at all eight Group × Word Pair combinations. For the native English speakers, the tongue was placed at significantly different positions for the first vowels in *able–ability*, *Satan–satanic*, *botany–botanical* but not *application–apply* ($p < .05$). For the native Spanish speakers, the only significant tongue position difference was for *able–ability* ($p < .05$).
Figure 5. The mean position of the tongue in the stressed (+STR) vowel in *botany* and the unstressed (-STR) vowel in *botanical* as spoken by English speaker E3 (upper left) and three Spanish speakers (S2, S4, S5).
Figure 6. The mean position of the tongue in the stressed (+STR) vowel in Satan and the unstressed (-STR) vowel in satanic as spoken by English speaker E1 (upper left) and three Spanish speakers (S2, S3, S6).
Figure 7. The mean position of the tongue in the stressed (+ STR) vowel in *application* and the unstressed (- STR) vowel in *apply* as spoken by English speaker E3 (upper left) and three Spanish speakers (S1, S6, S7).
Figure 8. The mean distances of the tongue from the hard palate (in mm) in stressed and unstressed vowels spoken in four English word pairs by native speakers of English (top) and Spanish (bottom); the brackets enclose ± one standard deviation.
To compare the magnitude of the tongue position differences in each word pair, a ratio of tongue heights was computed for each subject. One-way ANOVAs revealed that the ratios obtained for the English and Spanish speakers in *able–ability* (0.35 versus 0.34) and *application–apply* (1.04 versus 0.96) did not differ significantly. The English speakers had significantly larger ratios (thus larger tongue position differences) than the Spanish speakers in *Satan–satanic* (1.34 versus 1.04) and *botany–botanical* (1.68 versus 1.00) ($p < .05$).

**DISCUSSION**

### Native English Speakers

As expected, the English speakers unstressed the first syllable in *ability*, *satanic*, *apply*, and *botanical* and produced these syllables with reduced vowels. The only exception was the one English speaker who did not produce a reduced vowel in the first syllable of *botanical*. She realized this vowel as $[\circ]$, probably as a result of how the word was spelled. The native English speakers produced three distinct reduced vowels: a more open variant in *ability* and *apply*, $[\Lambda]$, a mid central vowel $[\varepsilon]$ in *botanical*, and a close central vowel $[i]$ in *satanic*. The palatalized $[i]$ in *satanic* may have resulted from carry-over articulation from the preceding $[s]$.

The transcriptions indicated differences between vowels that were largely supported by the instrumental data. The English speakers produced vowels with the expected tongue height differences in three word pairs. In agreement with the transcriptions, which indicated a difference in tongue position along the front–back dimension ($[\varepsilon]$ versus $[\Lambda]$), the tongue height differences measured in *application–apply* were nonsignificant.

The transcriptions of stress placement also agreed with the instrumental analyses. Syllables perceived as more stressed were implemented with longer duration and greater intensity than those perceived as unstressed. The average ratios of stressed to unstressed vowel durations was 2.9, which is greater than the ratios reported by Delattre (1966) and Klatt (1976) (1.6 and 1.9, respectively). The apparent divergence may be due to the fact that the earlier studies examined connected speech, whereas the present study examined isolated words.

### Native Spanish Speakers

The English speakers' performance indicated that they were familiar with the words elicited and/or possessed tacit knowledge of stress placement and vowel reduction in morphologically related words. The same was not true of the native Spanish speakers. One indication of their lack of knowledge derives from Table 1, which lists those instances in which the experimenter pronounced test words in the presence of Spanish speakers. Except for the modeling of *able*, which occurred first on the list and was used as part of the instructions for some speakers, all other instances of $x$ in Table
I reflect speakers' questions about the meaning or pronunciation of the words marked. As discussed later, modeling the test words did not have a systematic effect on the Spanish speakers' pronunciation. In order to discuss what knowledge the Spanish speakers brought to bear on the task of stress placement and vowel reduction in the words elicited, each word pair will be considered separately.

The Spanish speakers most closely resembled the English speakers in producing able—ability. The transcriptions and instrumental analyses showed that, like the English speakers, they unstressed the first syllable in ability and implemented the stress difference between able and ability by means of similar duration and intensity differences. They also resembled the English speakers in producing a vowel quality difference between able and ability. However, the Spanish speakers did not reduce the vowel in the unstressed syllable of ability. They produced an [a], rather than the low central vowel [ʌ] produced by the English speakers.

These observations raise several issues to be discussed later as the results for the other word pairs are examined. First, why did the Spanish speakers resemble the English speakers more closely in producing able—ability than in the other word pairs? Perhaps word familiarity played a role, but since actual L2 input data are unavailable, we can only speculate that frequency of occurrence may have an effect on stress placement and vowel change in morphologically related words. If performance does improve as a function of frequency of word use, this would suggest that L2 learners acquire morphophonological alternations on a word-by-word rather than a rule-governed basis.

Second, the fact that the Spanish-speaking group showed about the same vowel duration ratios in able—ability as the English-speaking group (2.8 versus 3.1) suggests that the rhythmic pattern of Spanish does not interfere with the implementation of the English stress contrast along the duration dimension. In Spanish, which is considered a syllable-timed language as opposed to stress-timed English, the average duration ratio of stressed to unstressed syllables is almost 20% smaller than in English, according to Delattre (1966).

Third, the fact that the Spanish speakers implemented a stress contrast in English with an English-like duration ratio in able—ability also indicates that shortening a vowel (and decreasing its intensity) is not a sufficient prerequisite for vowel reduction for Spanish learners of English. It seems that the Spanish speakers treated stress placement and vowel reduction in morphologically related English words as independent phenomena. Given their production of able—ability, one could hypothesize that English stress placement poses less of a learning problem than vowel reduction and that an English-like stress placement is a necessary, but not sufficient, prerequisite for vowel reduction in English.

Support for the assumption that lexical familiarity played an important role in the Spanish speakers' performance derives from a comparison of able—ability and Satan—satanic. Both between- and within-group differences were much greater in the latter pair. Two Spanish speakers did not stress the first syllable in Satan, suggesting they were unfamiliar with this English word and that they relied on the stress pattern of the Spanish cognate Satan. This may have resulted in smaller average duration and intensity ratios for the Spanish than English speakers in the first vowels in Satan and satanic.
The Spanish speakers’ highly variable production of these vowels (as opposed to those in *able* and *ability*) further suggests that they were less familiar with this word pair than with *able—ability*. Of the four women who heard the experimenter say *Satan* prior to the experiment, two (S3, S7) reproduced his diphthongal vowel [ei]. One (S5) apparently resorted to a Spanish-based reading pronunciation, producing [a]. Another one (S2) produced [ɛ], just like two other speakers who had not received any modeling for *Satan*. The remaining Spanish speaker (S6), who misplaced stress in *Satan*, was the only Spanish speaker in the entire experiment heard to pronounce the reduced vowel [ɔ]. However, she did not use a reduced vowel in all appropriate contexts, as can be seen from her production of the first vowel in *ability* and *botanical* (see also the discussion to follow). These observations lend further support to the hypothesis that stress placement and vowel reduction may be independent phenomena, at least for this L2 learner of English.

All speakers were heard to unstress the first syllable in *satanic*. However, the instrumental analysis indicated that the Spanish speakers shortened duration and lowered intensity less in *satanic* than in *ability*. Their uniform production of stress in *satanic* stands in contrast to their production of vowel quality. Three speakers produced a reduced vowel in most tokens. (Only one of them heard the vowel modeled.) Four Spanish speakers produced a full vowel which, in two instances, was identical to the first vowel heard in *Satan*. It again appears that the Spanish speakers were more successful in producing a stress difference than a vowel quality difference. Since it is unlikely that they heard *satanic* frequently, the Spanish speakers’ stress placement either reflects reliance on Spanish cognates (*satánico*/*satánica*) or mastery of the English rule that places stress on the syllable immediately preceding the suffix -*ic*.

The Spanish speakers differed most from the English speakers with regard to *application—apply*. The transcriptions and instrumental data showed that, unlike the English-speaking group, the Spanish-speaking group did not produce a stress contrast between the first syllables of these words. Two possible explanations can be offered for why the latter failed to stress the first syllable in *application*. They may have reacted to the multilevel stress system of English by treating all nonprimary stress levels equally, which would indicate reliance on the Spanish binary distinction of stress.9 Or, they could have relied on the stress pattern in the Spanish cognate *aplicación*, which is equally unstressed in the first three syllables.

Five of the Spanish speakers also differed from the English speakers in not producing a vowel quality difference between the first syllables of *apply—application*. However, the instrumental data revealed that they, like the Spanish speakers who were heard to reduce the vowel in *apply* to [ʌ], produced small tongue height differences (albeit in a direction opposite to that observed in the English-speaking group). This suggests that while only two Spanish speakers produced different vowels in the first syllables of *apply—application*, all members of the Spanish-speaking group were tacitly aware of a vowel alternation. This raises the question of whether the Spanish speakers had different tongue position targets for the first vowels in *apply* and *application* even though only two of them produced a perceptible difference in vowel quality.

The Spanish speakers’ productions of *botany—botanical* lend further support to the
hypothesis that stress placement poses less of a learning problem than vowel reduction, and that these two phenomena may be independent for Spanish learners of English. Five of the seven Spanish speakers were heard to produce an English-like stress difference in this word pair. The misplacement of stress by two speakers led to a smaller average duration ratio between the first vowels of *botany* and *botanical* for the Spanish than the English speakers. It is uncertain whether the Spanish speakers' English-like stress placement in *botanical* was due to reliance on the stress pattern of Spanish cognates (*botánico/botánica*) or reflects rule-governed or lexical learning of the English stress pattern.

Unlike most English speakers, the Spanish speakers did not produce a reduced vowel in the first syllable of *botanical*. However, the transcriptions suggest that at least three of them were aware of the vowel alternation. These three produced the half-open vowel [ə] in most tokens of *botany*, rather than the half-closed [ʊ] in *botanical*. Their productions of the first vowels in this word, which one would expect to be identical if the pronunciations had been based on Spanish letter-sound correspondences, suggest an awareness of the English vowel alternation in terms of differences in tongue height, though not in terms of centralization. The glossometric data revealed that two more speakers produced the vowels with different tongue configurations: S6 with a higher tongue position in *botany* than *botanical*, and S4 with a lower tongue position. Because of S4, and because the remaining two native Spanish speakers S2 and S5 produced these vowels with the same tongue configurations, the group mean values may have underrepresented some Spanish speakers' knowledge of the vowel alternation.

**SUMMARY**

The results of this study cannot be compared readily to other studies because of the new instrumentation used and because the morphologically related word pairs examined here were spoken in isolation, not in connected speech. Still, this preliminary study resulted in a number of interesting observations and suggestions for further research.

In a study of English word stress by native and nonnative speakers, Fokes et al. (1984) suggested that some L2 learners of English use inappropriate phonetic correlates to implement the contrast of stressed versus unstressed because they produced full instead of reduced vowels. Our findings do not support this view but instead lead to the hypothesis of a hierarchy of difficulty and an order of acquisition for L2 learners of English that is the reverse of the one implied by Fokes et al. (1984). We hypothesize that an English-like implementation of the stressed versus unstressed contrast is acquired earlier than vowel reduction in unstressed syllables, and that the ability to unstress vowels in English is a necessary, though not sufficient, prerequisite for their reduction. This hypothesis is supported by the finding that native Spanish speakers generally performed better with respect to stress placement and implementation of the stressed versus unstressed contrast than on vowel reduction.

As in previous studies investigating L2 learners' stress placement and/or vowel reduction in isolated words or connected speech (e.g., Adams, 1979; Adams & Munro,
1978; Fokes et al., 1984), word familiarity was not controlled for in the present study. The present results nevertheless suggest that nonnative speakers may produce familiar (or high-frequency) words like *able-ability* more authentically than less familiar words. Further research is needed to test this hypothesis. This would help determine what tacit knowledge L2 learners have of stress placement and vowel reduction and how they acquire these features of their L2.

In this study, we could discuss only briefly the likely bases of the nonnative speakers' performance. Was their pronunciation of morphologically related English words based on their native rhythmic and stress patterns, on the stress pattern in a specific Spanish cognate, or on English stress regularities? Or was it based on having learned the individual stress pattern as part of the lexical specification of a newly acquired English word? We found some evidence for lexical learning of stress placement and vowel change of high-frequency words, but certainly much more research is needed to determine whether L2 learners learn stress placement and vowel reduction in morphologically related words on a word-by-word basis or as rule-governed phenomena. This need not be a strict dichotomy since it would seem highly plausible that some alternations are stored individually, while others may be computed (see also Dressler, 1985).

One surprising result of this study is that one native speaker of English did not reduce vowels in all appropriate contexts. Like six of the seven Spanish speakers, this English speaker consistently produced the full vowel [o] in the first syllable of *botanical*. This raises the important question of how the input of L2 learners is structured with respect to vowel alternations. An assumption of this study was that the Spanish speakers had been exposed to numerous instances of appropriately reduced vowels in the speech of native English speakers. The use of a full vowel by one of the English speakers suggests that L2 learners may not receive input with vowel reduction in all appropriate contexts. It is conceivable that this phenomenon is relatively frequent in foreigner talk. If so, the low incidence of vowel reduction found in the L2 learners' speech may not directly indicate a learning problem but to some extent reflect the input they receive.

Finally, the hypothesis that stress alternations are learned more readily than vowel alternations should be tested further by examining vowel reduction and stress placement in the speech of L2 learners whose L1 has both fixed stress and reduced vowels since the hierarchy observed here might be due to L1 transfer rather than characterizing L2 learning in general.

In conclusion, this study has documented for the first time some of the difficulties native Spanish speakers have in implementing the stress and vowel differences distinguishing vowels in morphologically related English words. The study was limited in terms of the number of speakers studied and the number of word pairs examined but should provide a basis for more in-depth studies of this perceptually important aspect of L2 learning.

NOTES

1. One notable exception is Harris (1983), who uses three stress levels in his cyclic treatment of Spanish stress.
2. These differences seem at least in part to be due to the ambiguity of the term stress (level), which may be used either to denote physical properties of utterances (in which case a multilevel system is not supported by the phonetic facts, according to Ladefoged, 1975) or to reflect impressionistic judgments of syllable prominence which may be based on the hearer’s mental representation of abstract phonological forms (see Chomsky & Halle, 1968, p. 25, and Lehiste, 1970, p. 150).

3. Other dimensions on which much less research has been expended include vowel quality (Lehiste, 1970; Lieberman, 1967) and an as yet unidentified parameter suggested by Ando and Canter (1969).

4. For a review of linguists’ attitudes toward morphophonology, see Kilbury (1976) and Dressler (1985).

5. As mentioned earlier, F0 is perhaps the most important perceptual correlate of stress in Spanish as well as in English. F0 was not measured because the sampling rate used to acquire data (100 Hz) was too low to permit accurate measurements.

6. One anonymous reviewer suggested that the Spanish speakers’ stressed-to-unstressed vowel duration ratio was Englishlike for able—ability but not for Satan—satanic or botany—botanical because the durations of the vowels in Satan and botany were shortened by the transfer of a speech timing characteristic of Spanish into English, namely, the shortening of vowels preceded by a consonant. This explanation, which assumes that a difference in syllable speech timing exists between English and Spanish, cannot be confirmed or disconfirmed by the data presented here, nor can the possibility that the duration of the vowel in application was very short because vowels are shortened more in closed syllables in Spanish than English.

7. Although this study did not focus on the production of stressed vowels, it should be noted that the two groups also differed in that the native Spanish speakers did not diphthongize the first vowel in able as strongly as the native English speakers did according to the transcriptions, and did not assume two tongue positions in this syllable (as the native English speakers did) according to the glossometric data. Thus, the well-known fact that native Spanish speakers tend to monophthongize English [ei] although Spanish has the diphthong [eI] was confirmed instrumentally in this study.

8. Note that only one speaker heard the experimenter say ability prior to elicitation, which, considering the uniform results from the native Spanish-speaking group, indicates that modeling did not have an effect in this instance.

9. A post-hoc analysis of the English speakers’ stress pattern in application revealed that they used three stress levels: primary stress on the penultimate, secondary stress on the first syllable, and no stress on the ultimate and antepenultimate. This auditory impression was supported by the instrumental data, which showed that the magnitudes of duration and intensity ratios between the first syllables in this word pair were smaller than those in the other word pairs, which were not perceived to have secondary stress on a first syllable.

10. Note that only two speakers from this group, who were heard to misplace stress in botany, were among the four who heard the experimenter say this word prior to the experiment. One of these, S3, was the only one who placed stress variably in a test item (botany) and who produced one token of a stressed syllable that was unstressed in the native English speakers’ productions, that is, the first syllable of botanical.

11. It is possible that the use of written stimuli to elicit data may have led to an underestimation of the L2 learners’ ability to reduce English vowels. In order to avoid the influence of spelling pronunciations, future studies of vowel reduction and stress placement should avoid written presentation of stimuli. It will also be important to examine speech behavior in conversational speech both instrumentally and by means of careful phonetic transcriptions.

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