



Generating iso-accented stimuli for second language research: methodology and a dataset for Spanish-accented English

Rubén Pérez-Ramón¹, Martin Cooke², María Luisa García Lecumberri³

¹Waseda University, Tokyo, Japan

²Ikerbasque, Bilbao, Spain

³University of the Basque Country, Vitoria-Gasteiz, Spain

rperez.ram@gmail.com, m.cooke@ikerbasque.org, garcia.lecumberri@ehu.es

Abstract

A non-native accent can be conveyed at both the segmental and suprasegmental level. Previous studies have developed techniques to isolate the effect of segmental foreign accent by splicing accented segments from a bilingual speaker into non-accented words produced by the same speaker. The current work addresses the issue of between-segment variability by developing a technique to convert from acoustically-equal accent gradations to perceptually-equal steps. The procedure is used to derive the first corpus of Spanish-accented English composed of lexical tokens each generated with one of five degrees of non-native accent. As an example application, corpus tokens are used to elicit accentedness judgements from four listener cohorts with first languages which differ as to whether they share the native language, the non-native (accented) language of the corpus or have a closer phonological inventory to one or the other. Findings highlight the importance of the relationship between listeners' phonological systems and those of the native and non-native languages of the corpus, especially for vowels, with respect to sensitivity to foreign accent.

Index Terms: segmental foreign accent, Spanish, English

1. Introduction

Non-native speakers may be perceived by native listeners as having a foreign accent (FA) due to the presence of features in their speech which differ from native standards. While non-native speech has traditionally been studied from a holistic point of view, e.g. [1, 2, 3], it is now known that the perceived strength of a FA can be caused by a diversity of cues. A number of studies have looked at the effects of suprasegmental characteristics of FA [4, 5, 6, 7], but in recent years the segmental domain has received increased attention e.g. [8], in part due to advances in computational techniques such as Deep Neural Networks [9]. Some models have investigated the perception and production of non-native segments [10, 11, 12]. Nevertheless, the practical implications of segmental as opposed to 'holistic' FA remain mostly unexplored. The current study contributes new methodological and data resources to the study of segmental foreign accent and demonstrates their application to the perception of Spanish-accented segments in English words.

Our approach to isolating the segmental impact of FA involves generating tokens in which a single segment is produced with an accent. Previously [13] we explored three techniques for the generation of segmental FA: code-switching, in which a bilingual speaker produced words by replacing only one segment with its accented counterpart; splicing, where a segment was manually replaced via signal manipulation; and synthesis of segmental FA via HMMs. Out of the three techniques, splicing

was found to be the most robust in terms of reliability and token quality. Subsequently, in [14] splicing was used as the basis for a gradation technique in which native and non-native realisations were blended to produce a continuum of phonetic segments varying in degree of accentedness.

One finding from [14] was that equal amounts of acoustic manipulation did not in general lead to equal-sized changes in nativeness judgements. While some segments exhibited a near-linear relationship between acoustic degree of manipulation and perceived nativeness, for most this was not the case. Fig. 1 depicts some of the patterns found in the current study (see Sec. 3).

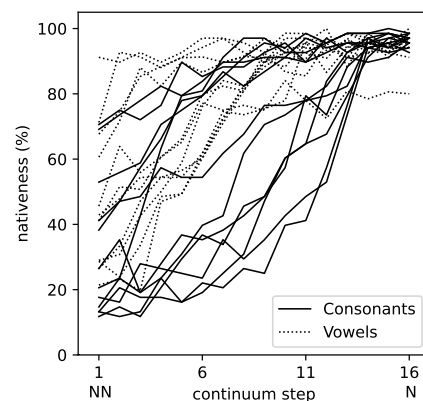


Figure 1: Patterns of perceived nativeness (rated by native listeners) as a function of degree of acoustic manipulation. Each line corresponds to a continuum from Table 1. Some sounds lead to rapid changes in perceived nativeness, others remain native-like throughout, while some show a quasi-linear relationship with continuum step. N and NN indicate the native and non-native (accented) ends of the continuum.

While these different acoustic-perceptual patterns may be of interest in themselves, their inherent variability is potentially problematic for studies into the impact of non-native speech. Inter-segment variability is a source of noise that might reduce sensitivity to relevant contrasts. This concern is made more acute by the limited number of segments in a language, leading to the possibility that outcomes will depend strongly on the choice of segment subset. Further, characterising the acoustic-perceptual relationship requires a continuum with many steps, leading to a time-consuming experimental procedure.

The main methodological contribution of the current paper is the development of a procedure (Sec. 2) that linearises the relationship between the degree of acoustic manipulation and its perceptual impact, whose goal is to produce gradations that

are iso-perceptual rather than iso-acoustic. The procedure is applied to the creation of an open corpus of Spanish-accented English words (Sec. 3), and illustrated in a study of the perception of segmental foreign accent for four cohorts differing in their first language (Sec. 4).

2. From iso-acoustic steps to iso-perceptual effects

The goal is to identify a small number of acoustic exemplars, separately for each accented-to-native continuum, which lead to equally-spaced accentedness judgements. The procedure involves four stages. In the first, an accented-to-native continuum of exemplar words is generated for a given consonant or vowel segment. In the next stage, accentedness judgements for the entire continuum are elicited from a native speaker cohort. A generalised logistic function is then used to model the relationship between acoustic and perceptual degrees of accent. Finally, this functional form is inverted and a fixed number of acoustic exemplars are generated for specific degrees of accent. This procedure is illustrated in Fig. 2 and detailed below.

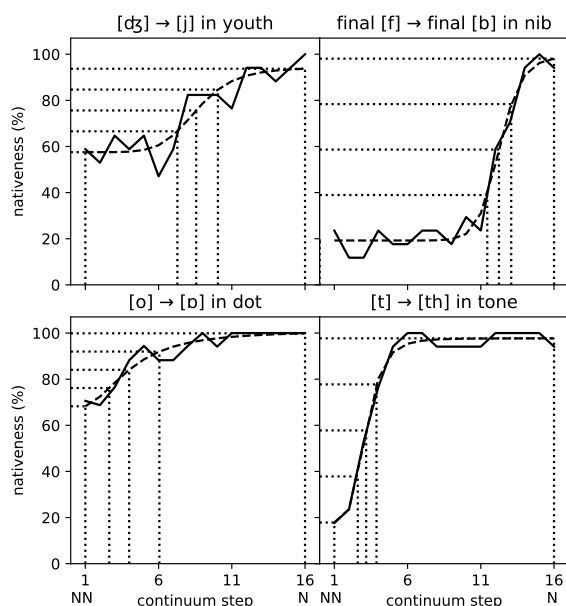


Figure 2: Examples of 16-step acoustic continua (x-axis) and the nativeness judgements they elicit (y-axis). Segments are indicated as [non-native]→[native]. Solid lines depict raw judgements, dashed lines represent logistic fits, horizontal lines identify 5 equally-spaced perceived accentedness levels, while vertical lines indicate acoustic degrees of modification corresponding to these levels.

The starting point for creating words with a graded degree of segmental foreign accent is the generation of a continuum of exemplars which differ in a single consonant or vowel segment. One end of the continuum is formed from the native production, while the non-native end is generated by splicing an appropriate segment into the native production. For example, [xaʊs] represents a strongly Spanish-accented version of the English word “house”, and can be generated by combining a token of /x/ produced in a nonsense-word context with [aʊs] extracted from the native production. The method developed in [14] de-

scribes how the intermediate members of the continuum can be generated using an acoustic weighting procedure. The end result is a continuum with equal-sized acoustic steps which can be made as fine-grained as required. For the procedure introduced here it is necessary to have sufficient steps to enable a robust fit to accentedness judgements made by native listeners. The solid lines in Fig. 2 show across-cohort listener judgements of nativeness for four such continua involving accented segments.

A 4-parameter logistic function (eq. 1) is sufficiently expressive to capture patterns of nativeness judgements. This function is fitted to the results of the nativeness categorisation task to highlight the underlying perceptual pattern, enabling the prediction of perceived nativeness at any step of a hypothetically infinite [non-native]→[native] continuum. Dashed lines in Fig. 2 show logistic fits for four continua.

$$f(x) = d + \frac{a - d}{1 + \left(\frac{x}{c}\right)^b} \quad (1)$$

Some foreign-accented segments do not convey a complete lack of nativeness, and they might be perceived by native listeners as a close realisation of the native segment. For example, the lower left panel of Fig. 2 indicates that even the most strongly-accented native Spanish realisation of English /b/ results in a relatively high degree of nativeness. As a result, the perceptual range of a [non-native]→[native] continuum is taken to run from the lower limit of *perceived* nativeness (i.e. 0% of the possible perceived nativeness for that particular [native] target segment) to the higher limit of *perceived* nativeness (i.e. 100% of the possible perceived nativeness). The transformation to iso-perceptual steps proceeds by dividing the range between the upper and lower limits of the logistic fit to nativeness judgements into a fixed number of equal-sized steps (indicated by the horizontal dotted lines in Fig. 2), with the extremes of the range coinciding with the upper and lower limits themselves. The corresponding acoustic steps (vertical dotted lines in Fig. 2) can then be found by evaluating the inverted best logistic fit. Acoustic steps do not in general coincide with the (integer-valued) steps of the original continuum, but this does not present a problem since the accent generation method [14] operates with non-integer steps.

3. The SIAEW Corpus: a corpus of Spanish-Iso-Accented English Words

The iso-accentedness procedure described in Sec. 2 was used to generate a dataset of Spanish-accented English words, which we call the SIAEW Corpus.

Twelve target consonants were chosen from the English consonant inventory. The English glottal fricative [h] was selected because it is typically realised as velar [x], a sound absent in the English system. Similarly, the English rhotic [ɹ] is characteristically pronounced with a Spanish trill [r] [15]. The English voiced fricatives [v] and [z] were included since Spanish does not have voiced fricative phonemes [16]. The two English categories [dʒ] and [j] are realisations of a single category in Spanish [17]. The English fricative [ʃ] only appears in loan words in the Spanish variety of the study. Two English voiceless plosives ([t^h] and [k^h]) were chosen since aspiration is not distinctive in Spanish [18]. English word final voiced plosives were included because they are problematic for Spanish speakers: the only word final voiced plosive in Spanish ([d]) tends to be fricated and devoiced and by analogy the same process

Table 1: *Continua used in the SIAEW Corpus. Each row defines the end points of the continuum and the four words into which the accented segment is spliced. Consonants are in initial position except for those preceded by an underscore.*

Native	Accented	Words
h	x	help, hide, hole, house
ɹ	r	red, rent, rhyme, risk
k ^h	k	cast, code, cold, kiss
t ^h	t	town, tile, toad, tone
v	b	van, veil, valve, view
ʃ	s	shoe, short, shape, sharp
z	s	zap, zone, zoo, zoom
ɔ̃	j	jam, jaw, June, jest
j	ɔ̃	yak, yoke, years, youth
ˌb	ˌf	cab, nib, rib, crab
ˌd	ˌθ	god, load, dad, food
ˌg	ˌx	dog, frog, leg, smog
ɜː	e	bird, burn, firm, learn
ɜː	o	word, world, worm, worse
æ	a	back, cat, clap, pact
ɑː	a	fast, raft, shark, stark
ɪ	i	clip, mist, pick, sin
iː	i	beam, seem, steam, team
ɒ	o	cost, dot, pot, spot
ɔː	o	clause, fall, orb, storm
ʊ	u	look, nook, put, should
uː	u	choose, mood, moon, spoon

affects [b] and [g] in borrowings and in accented English.

The English vowel space is densely populated in comparison with the Spanish space [19]. In this study we pair 9 English vowels with one of the 5 Spanish vowels most likely to be used in their accented realisation. In the case of the central vowel [ɜː] a second vowel continuum was created corresponding to the Spanish vowel suggested by orthographic rules, since spelling is a strong factor in Spanish foreign accented English.

For some of the selected English segments, the corresponding Spanish-accented sound is also a good exemplar of a different phonological category in English (e.g. in the [b]/[v] contrast, both segments are good exemplars of different phonemes in English). For this kind of segment, the decision was taken to include at least one word that would generate a minimal pair (e.g. *ban/van*) and at least one that would not (e.g. **biew/view*). In the case of the consonant pairs [x]/[h] and [ˌx]/[ˌg], the foreign accented segment ([x]) is not a good exemplar of any English phoneme, so no minimal pairs were expected for these continua. Given the acoustic characteristics of the plosives [20], Spanish [p], [t], [k] (voiceless plosives) may be perceived as [b], [d], [g] (voiced plosives) respectively by an English listener. Therefore, Spanish segments [t] and [k] were considered as possible realisations of English [d] and [g] respectively for the purpose of minimal pair selection.

Generation of accented stimuli using the method introduced in [14] requires the recording of word and nonword tokens from bilingual speakers with minimal accent in either language. Such individuals are exceedingly rare. For the SIAEW Corpus, five candidate bilinguals (one male) with ages in the range 18-25 years were evaluated using a two-step procedure. First, speakers read newspaper articles in English and Spanish, on the basis of which one speaker was excluded as having a perceivable accent in one language. Second, the remaining four speakers read both the English word list in Table 1 and an additional list of Spanish non-words. Each speaker produced 3 versions of each item from which one was chosen for acoustic manipulation after considering factors such as absence of background noise and

voice clarity. Continua with 16 steps were generated for each of the 88 words following the procedure in [14].

A cohort of 17 native English listeners categorised members of each continuum as native or non-native. Participants were drawn from the student population at Anglia Ruskin University (Cambridge, UK); none had knowledge of Spanish beyond the A1 level (beginner, [21]) and were not bilingual in any language nor had lived for extended periods in locations with a different language or strong regional accent. All passed a pure-tone audiometric screening. The task was a two alternative-forced choice procedure in which participants categorised each of the presented tokens as either foreign-accented or native. Stimuli were presented in a quasi-random fashion, with no consecutive same-continuum steps. Tokens were blocked by speaker and type of target segment (i.e., consonants or vowels). Each listener made 5632 judgements (22 continua \times 16 steps \times 4 words \times 4 speakers). The experiment was generated using the experimental interface of Praat [22], lasted around two hours, and took place in two sessions on different days.

Listener responses with reaction times below 300 ms and above 5000 ms (under 1% of responses) were removed from the analysis. Speaker differences were evaluated statistically in R [23] via a generalised linear mixed-effects model using the `glmer` function of the `lme4` package [24], with `SPEAKER` and `STEP` as fixed factors and with `PARTICIPANT` and `SEGMENT` as random factors. The importance of retaining factors in interactions and main effects was determined by model comparison using the `anova` function; we report χ^2 statistics and p-values resulting from model comparison. Post-hoc analysis involved pairwise contrasts with Tukey corrections for multiple comparisons using the `emmeans` package [25]. Separate analyses were performed for consonant and vowels.

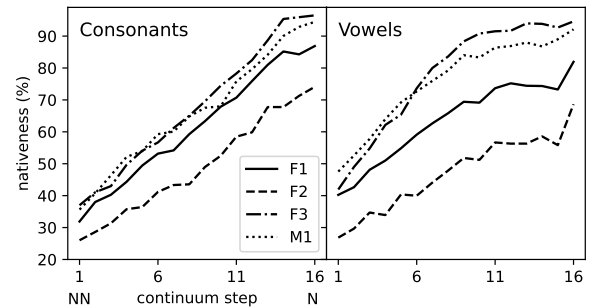


Figure 3: *Native listener categorisation outcomes for the four speakers across all consonants and vowels. Error bars have been omitted for clarity.*

Fig. 3 shows mean nativeness categorisation judgements. For both vowels and consonants, `SPEAKER` interacted with `STEP` [vowels: $\chi^2(45) = 414, p < .001$; consonants: $\chi^2(45) = 360, p < .001$]. It is apparent that tokens elicited by speaker F2 convey a marked degree of accent for both consonants and vowels, while speaker F1 also exhibits accentedness, especially for vowels. Considering just the native end of the continuum (step 16), speakers F3 and M1 did not differ statistically for vowels [$p = .21$] or consonants [$p = .32$] but differed from speakers F1 and F2 [all $p < .001$ for both vowels and consonants]. Based on these findings, tokens generated from speakers F1 and F2 were considered not suitable for foreign accent evaluation, while both speakers M1 and F3 reached nearly 100% of perceived nativeness at the native end

of the continua. Materials produced by speakers M1 and F3 were therefore used as the basis for the SIAEW Corpus. Using the procedure described in Sec. 2, five equally-spaced accented tokens were produced for each of the 88 words spoken by these two speakers. The SIAEW Corpus consists of the resulting 1056 accented word tokens (2 speakers \times 22 segments \times 4 words \times (5 steps + original native token)). The Corpus is available for download with an unrestrictive licence at <https://doi.org/10.5281/zenodo.6371655>.

4. Segmental foreign accent for listeners with differing L1s

To illustrate one application of the SIAEW Corpus, this section presents accent ratings by four listener cohorts with different first languages (Table 2). It has already been demonstrated that English and Spanish listeners perceive Spanish segmental foreign accent in English words in dissimilar ways [26]. The experiment described here includes two additional cohorts whose L1 is neither that of the target word nor that of the accented segments. The L1 of the Czech listener group has relatively more similarities to the English phonological system than to the Spanish one. On the other hand, the L1 vowel system of the Japanese cohort is more similar to Spanish than to the English or Czech inventories.

Table 2: Cohort details.

L1	N	Age	Location
Czech	14	21.8	Charles University, Prague
English	22	23.5	Anglia Ruskin Univ., Cambridge
Japanese	25	21.4	Waseda University, Tokyo
Spanish	24	19.4	Univ. of the Basque Country, Vitoria

Stimuli for the experiment consisted of the 88 words at each of the 5 accent levels for the female speaker of the SIAEW Corpus. The categorisation task was a two-alternative forced choice design, in which participants were asked to decide whether each of the 440 stimuli was pronounced with a foreign accent or with a native accent. Since some of the accented forms are real words in English (e.g. an accented production of the word “van” could be the real word “ban”), the orthographic form of the target word was presented on-screen.

Stimuli were presented in two blocks, one for consonants and one for vowels, and these two blocks were tested in a random order across participants. Within blocks, stimuli were arranged in a pseudo-random order, with no consecutive same-continuum steps. Participants were aware that stimuli could not be repeated, and that once one of the two options was selected, the next stimulus would automatically be reproduced. Participants had a 1-minute break between blocks. Statistical model comparison followed the procedure outlined in Sec. 3, with COHORT replacing SPEAKER.

Fig. 4 plots mean nativeness ratings for each cohort as a function of continuum step. While all cohorts display a monotonic relationship between continuum step and the likelihood of reporting a token as native, the pattern of this relationship differs across cohorts, especially for vowels. Statistical models reveal a clear STEP \times COHORT interaction for both consonants [$\chi^2(12) = 125, p < .001$] and vowels [$\chi^2(12) = 232, p < .001$]. For consonants, the three non-native cohorts were less confident in treating native tokens (step 5) as native than the English cohort [Czech: $p < .05$; Japanese, Spanish $p < .001$] while the Spanish treated the most accented tokens (step 1) as

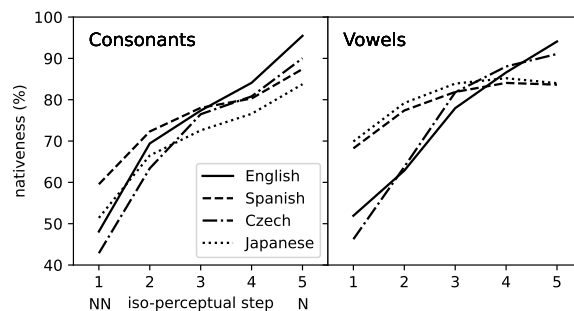


Figure 4: Mean nativeness judgements for words containing a single accented consonant or vowel for four listener cohorts at 5 equal perceptual steps along a non-native/native continuum.

less-accented [$p < .01$], possibly due to accent familiarity. For vowels, a clear difference between the Czech/English and Spanish/Japanese cohort pairs can be seen, with the former pair identifying native vowels (step 5) as less-native than the latter pair [$p < .05$] while treating accented vowels as more native-like [$p < .05$]. We hypothesise that this disparity originates from differences in the vowel inventories, leading to a difficulty in reliably deciding whether a vowel segment drawn from a much larger set than one’s native set is native or not.

5. Discussion

Previous research has shown that foreign-accented realisations may or may not fall within the scope of what is considered an acceptable exemplar of a native pronunciation [27], and that the consequent degree of perceptual FA fluctuates across segments [13]. This variability inspired the normalisation procedure proposed here. The perceptual normalisation of acoustic differences within accented-to-native continua enables an experimenter to elicit the desired amount of perceived accentedness for native listeners in each segment, by specifying the required degree of blending between native and non-native realisations of a target sound. Quite apart from allowing control over accentedness, the proposed approach removes the requirement to sample the acoustic continuum at a fine detail, and obviates the need to test multiple speakers to elicit a specific degree of foreign accent, unlike earlier studies, e.g. [28].

As a specific application of the normalisation procedure, we introduce a new open resource for segmental-level studies of Spanish-accented English, the SIAEW Corpus, and demonstrated its use in a perceptual experiment with four listener cohorts varying in L1 phonological resemblance to the native and non-native languages. The normalised corpus allowed similarities and differences across these listener groups to be highlighted. It was shown that in the case of vowel perception, it is the size of the listeners’ L1 inventory and not language distance that explains perceptual accuracy in detecting foreign accent.

The normalisation method presented here can be applied to other languages and accented varieties and may thus help in depth research into the perceptual effects of segmental foreign accent and the role of the first language phonological system in the perception of specific foreign accented segments.

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